Jet Propulsion Laboratory
California Institute of Technology

The Power of the Mars Program

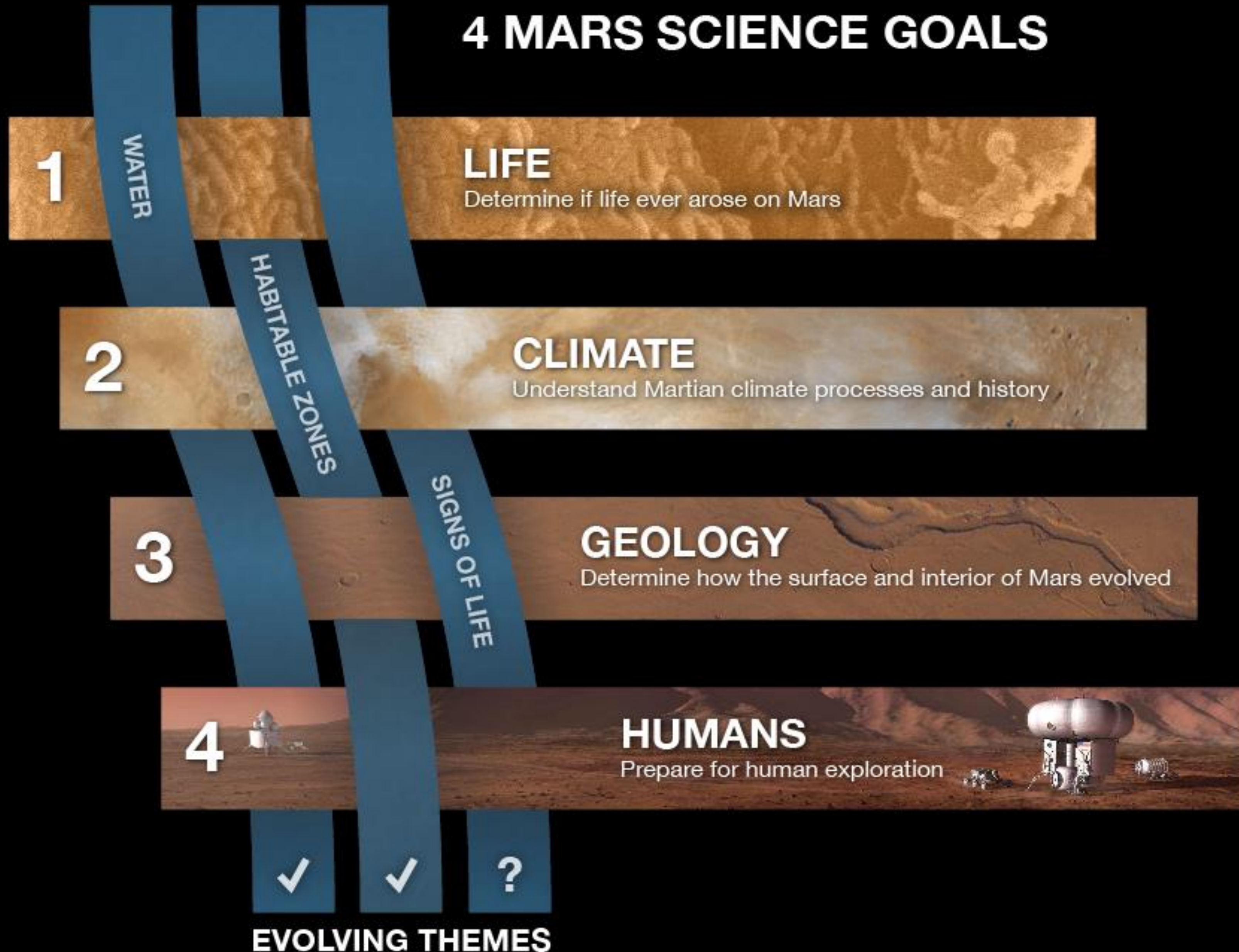
University of Michigan

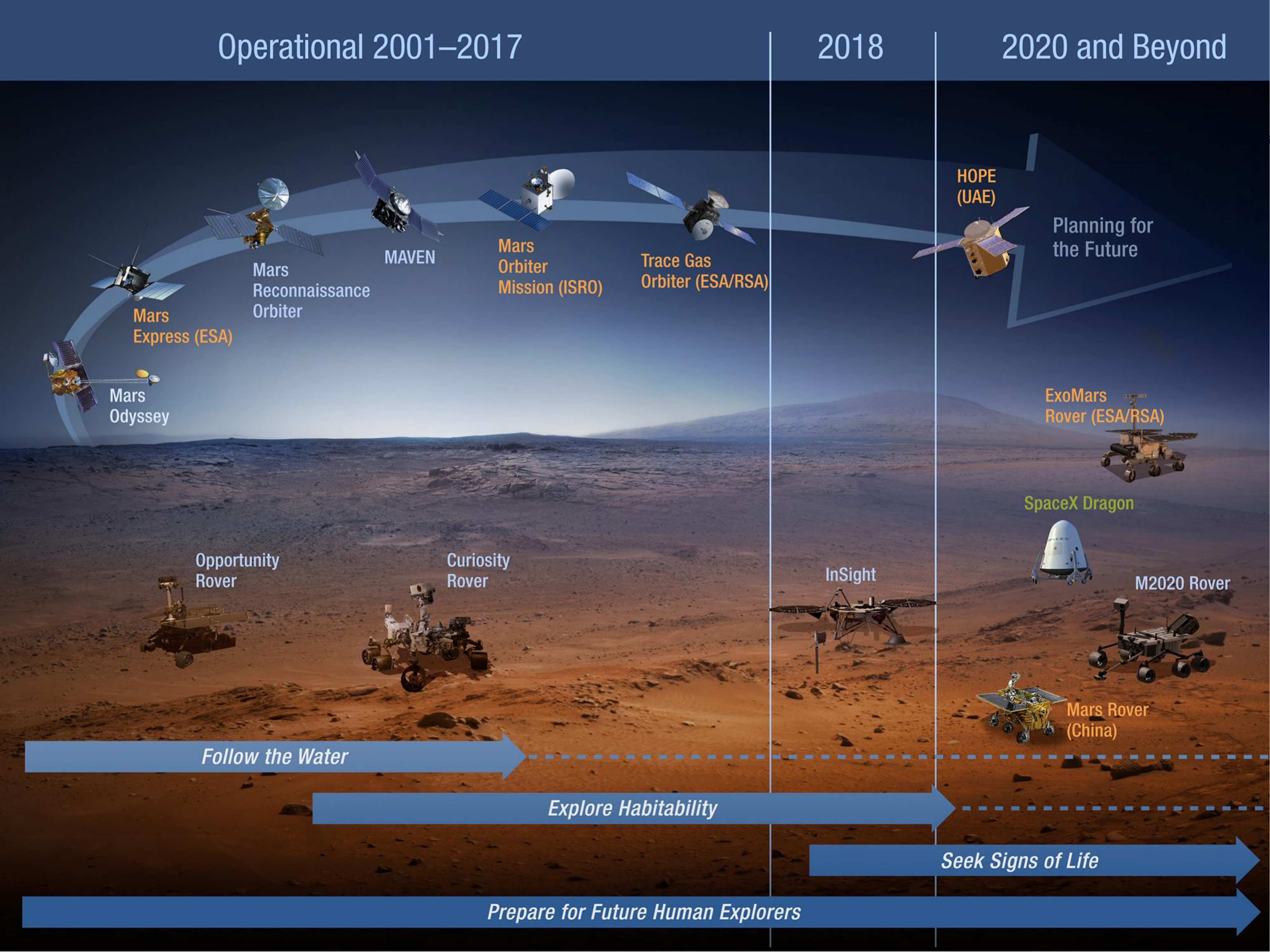
April 5, 2017

Leslie K. Tamppari
Deputy Project Scientist, Mars Reconnaissance Orbiter

Outline

- Intro slide and my background
- Overview of Mars Exploration Program (5)
- Interaction between the projects – Intro slide
  - Science, Landing sites seection, Areobraking, Landing support, Relay
- MRO is key player
  - Instrument overview
  - How these data are used in
    - Science
    - Landing site selection and safety
    - Aerobraking and landing
  - Recent results
    - ExoMars EDM
    - InSight
    - ExoMars
    - 2020 (NASA and ESA)
    - Red Dragon
- NASA 2020 – three final sites
  - Show them
  - Science overview of the mission
  - Instrumentation
- Summary

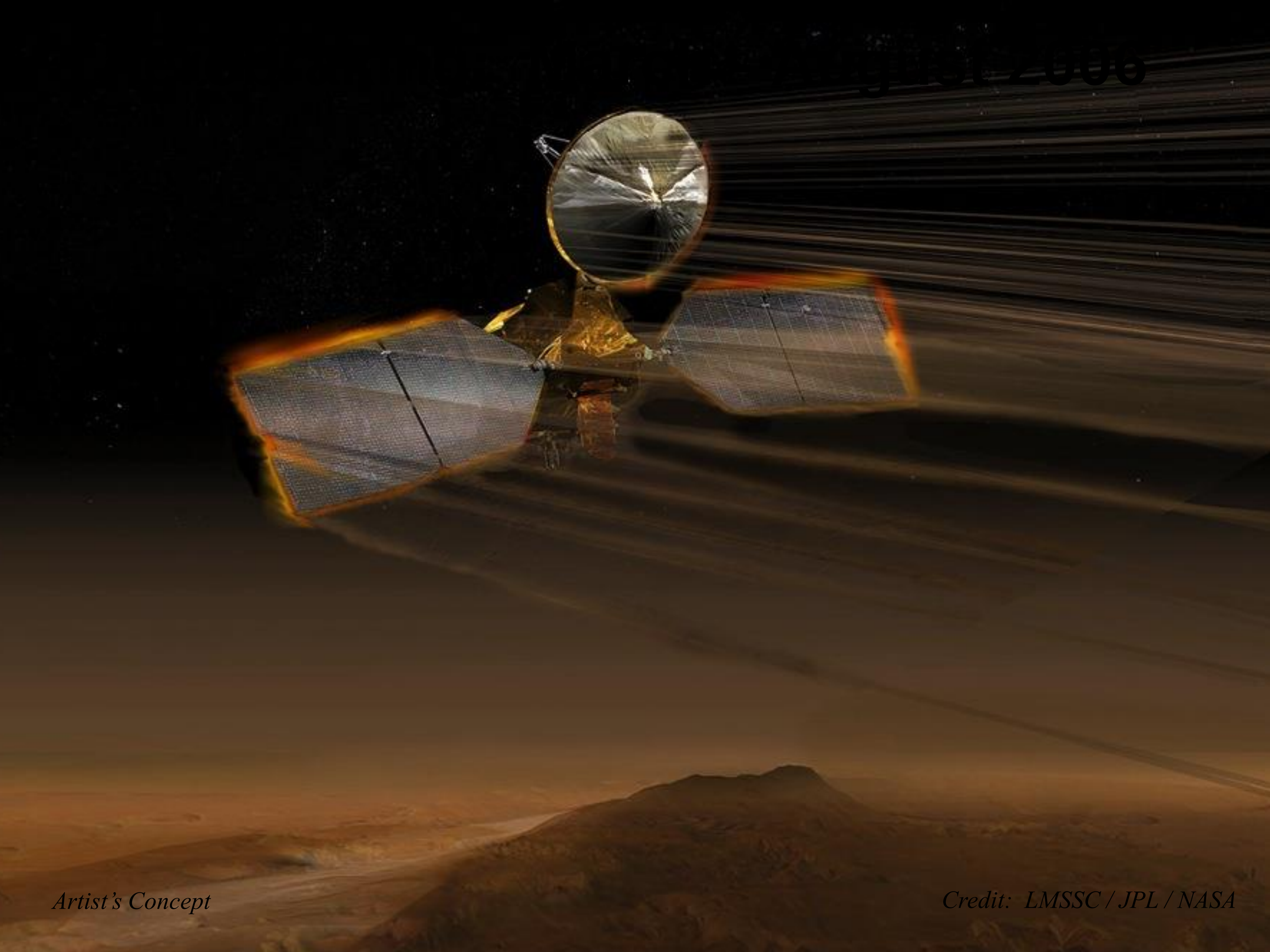

4 MARS SCIENCE GOALS
1
LIFE
Determine if life ever arose on Mars
2
CLIMATE
Understand Martian climate processes and history
3
GEOLOGY
Determine how the surface and interior of Mars evolved
4
HUMANS
Prepare for human exploration
WATER
HABITABLE ZONES
SIGNS OF LIFE
✓
✓
?
EVOLVING THEMES



Operational 2001–2017
2018
2020 and Beyond
Mars Odyssey
Mars Express (ESA)
Mars Reconnaissance Orbiter
MAVEN
Mars Orbiter Mission (ISRO)
Trace Gas Orbiter (ESA/RSA)
HOPE (UAE)
Planning for the Future
ExoMars Rover (ESA/RSA)
SpaceX Dragon
M2020 Rover
Mars Rover (China)
Opportunity Rover
Curiosity Rover
InSight
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

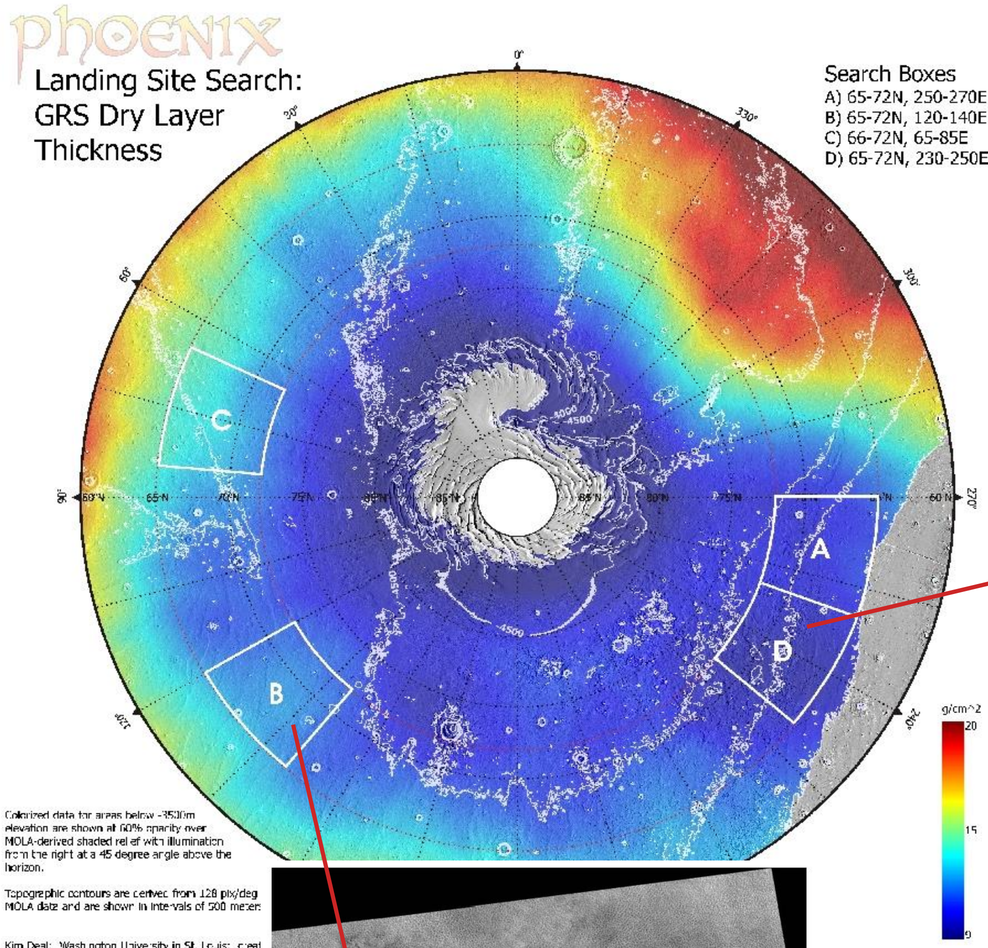
Interaction between spacecraft

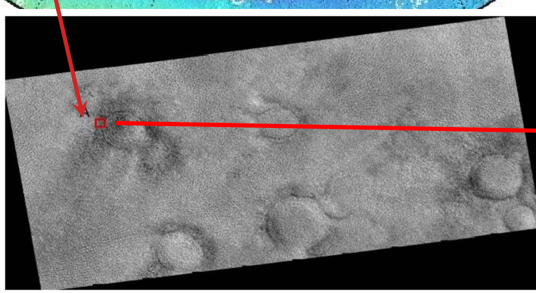
- Science, Landing sites seection, Areobraking, Landing support, Relay


Artist's Concept
Credit: LMSSC / JPL / NASA

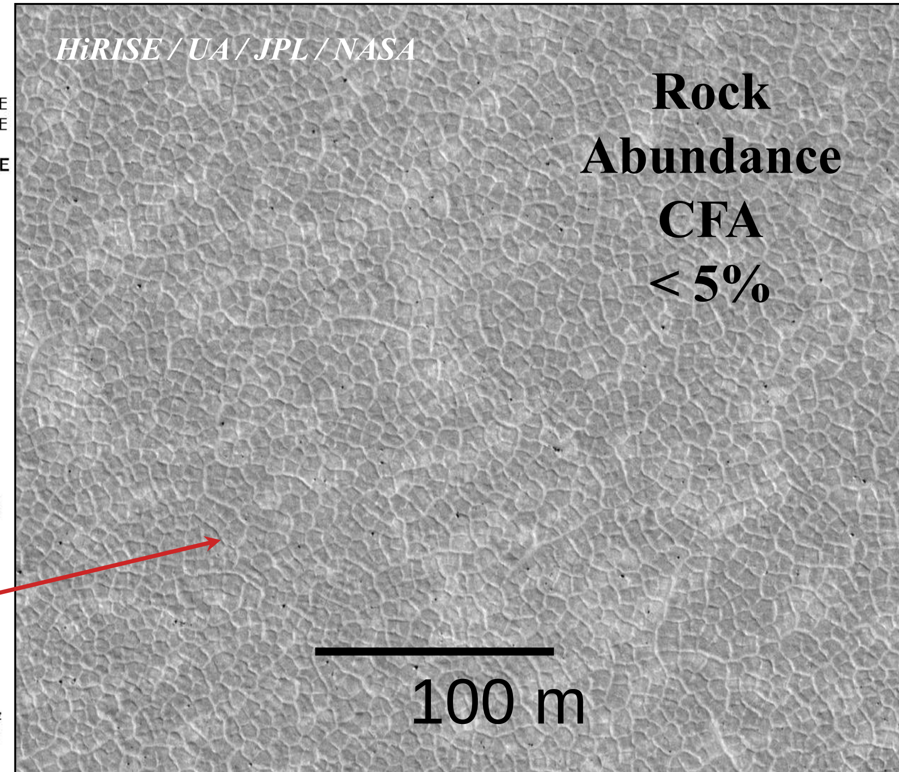
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

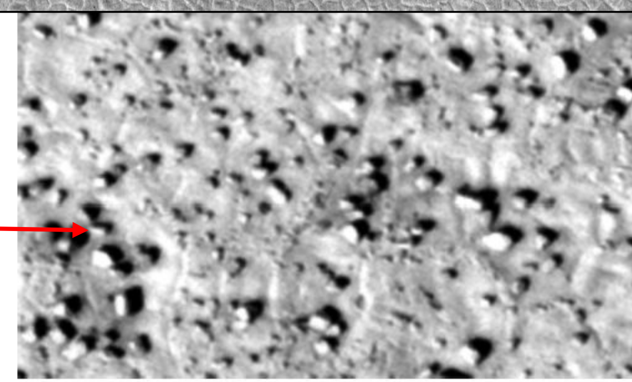
Support of other missions:
Landing site selection, characterization, certification





xstart: 5619
Ystart: 6078





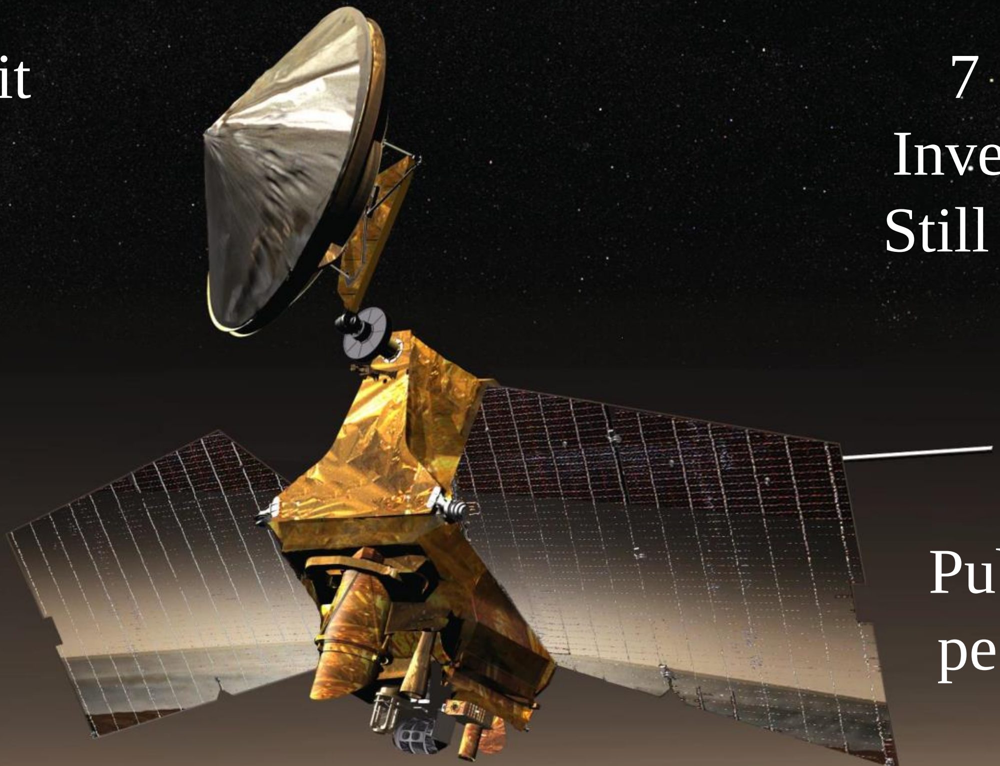
Rated "Excellent" in 2016 Planetary Mission Senior Review

11 Years in Orbit

~50,000 orbits

300 Tb of Science Data Returned

~200 kg of Usable Fuel still in the Tank



7 Science Investigations Still Returning Data

~1000 Publications in peer-reviewed Journals

Mars Reconnaissance Orbiter

Government sponsorship acknowledged.

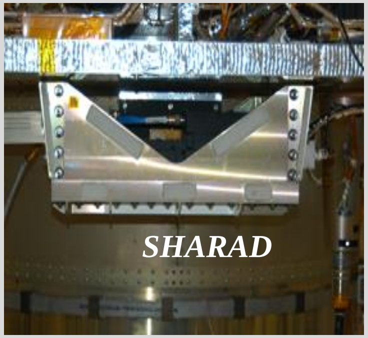
MRO Science Investigations

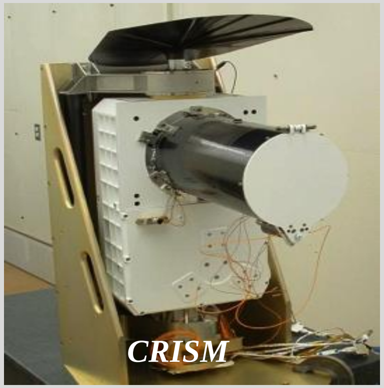
HIRISE

~49,000 images
(~5000 stereo)
~2.8% of Mars
RSL, Gullies,
Dunes, Polar Caps

SHARAD

~21,000 Observing Strips
Buried CO_2 Ice
Polar Cap Internal
Structure
Mid-latitude Ice





CRISM

~85% msp IR
~39% hsp IR
~76% hsp VNIR
Limb Scans
Ancient Aqueous Minerals
ATO's (6-12 m/pixel)

MCS

~150 M Soundings
~94% of 5.4 MYrs
Vert. Dust Profiles
Dust Storm Patterns
Tidal Structure
CO2 snow and frost

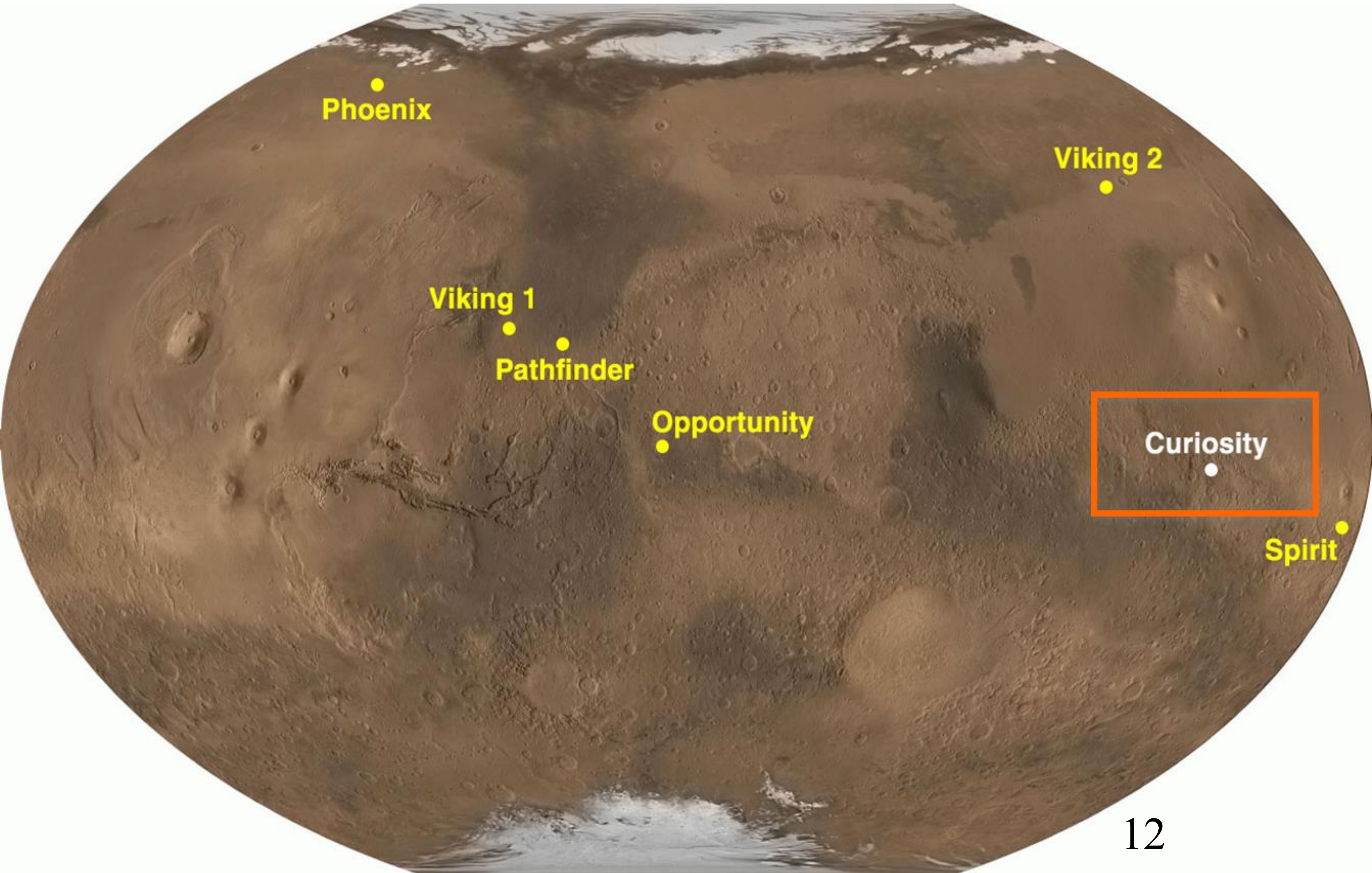
CTX

~92,000 images ~99% of
Mars 20% in dual
coverage
Stratigraphy
New Impacts

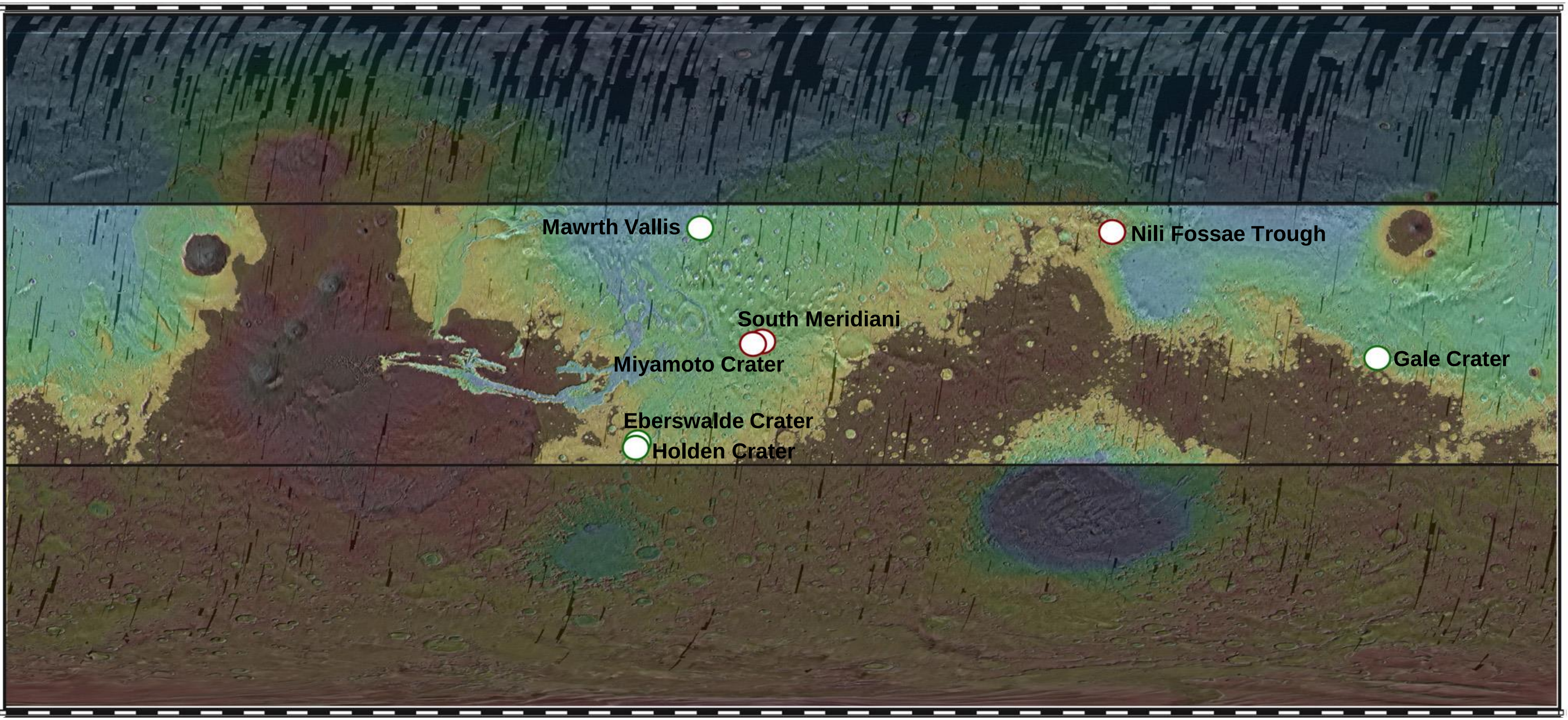
MARCI

~47,000 images
5.4 Myrs
~3600 Daily Global Maps
Dust & Ice Clouds
Dust Storm Tracks

Mars Landing Sites



Seven Downselected MSL Landing Sites:



Seven Sites Receiving Highest Science Ranking:

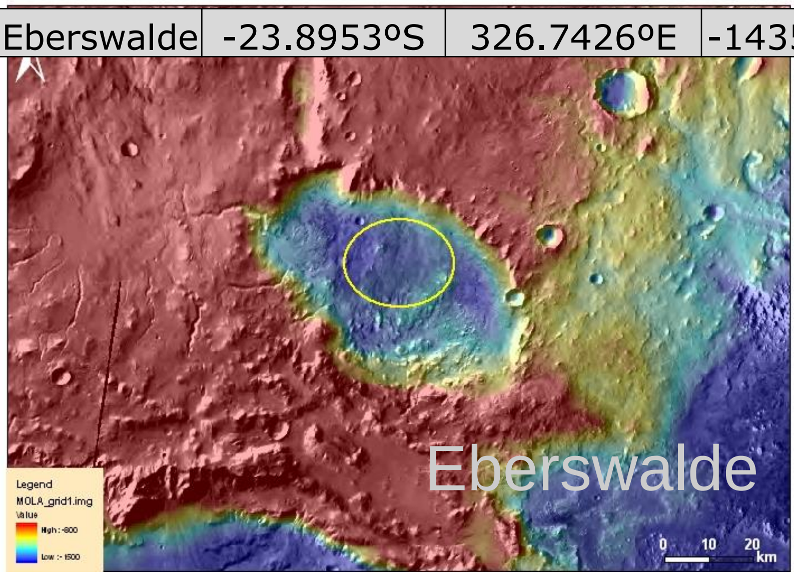
Shaded areas poleward of 30° , elevations >1 km

Green outlines denote final four sites based on science, engineering

Final Four MSL Landing Ellipses

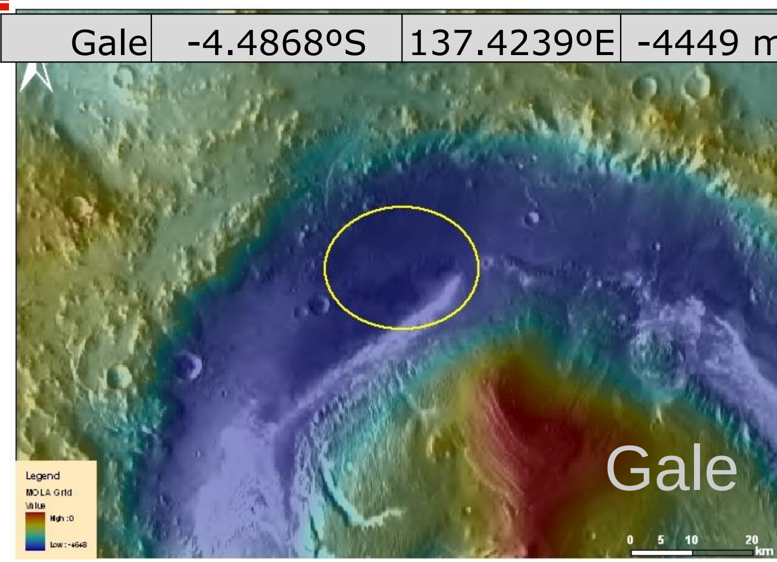
Eberswalde Crater: MOLA

Eberswalde	-23.8953ºS	326.7426ºE	-1435 m



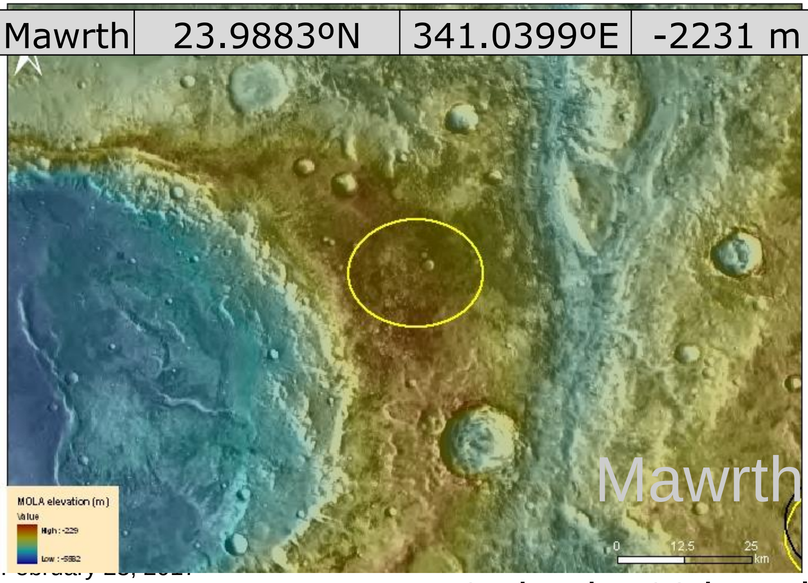
Gale Crater: MOLA

Gale	-4.4868ºS	137.4239ºE	-4449 m



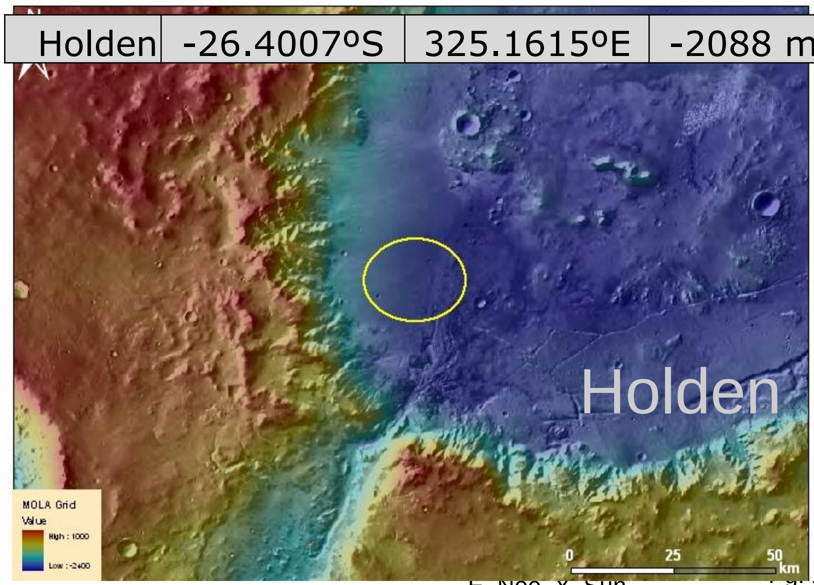
Mawrth Vallis Site 2: MOLA

Mawrth	23.9883ºN	341.0399ºE	-2231 m



Holden Crater: MOLA

Holden	-26.4007ºS	325.1615ºE	-2088 m

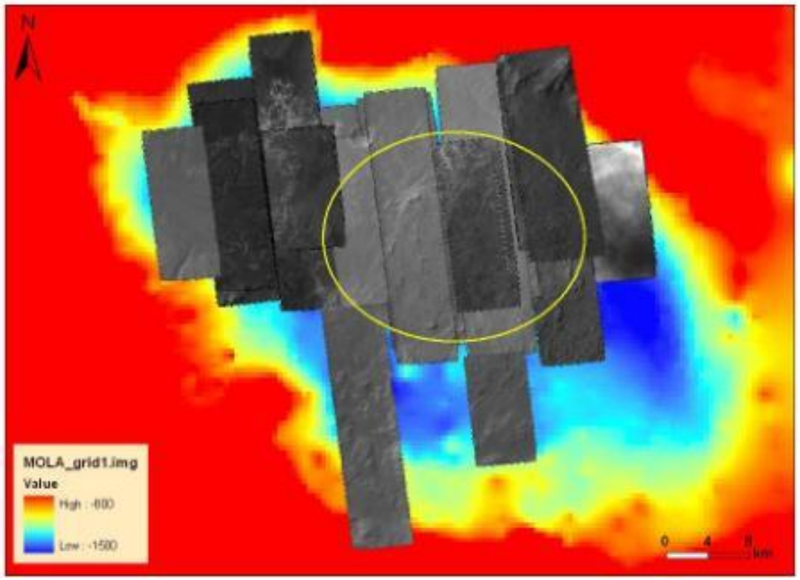


25 km by 20 km Ellipses E-W for 2011

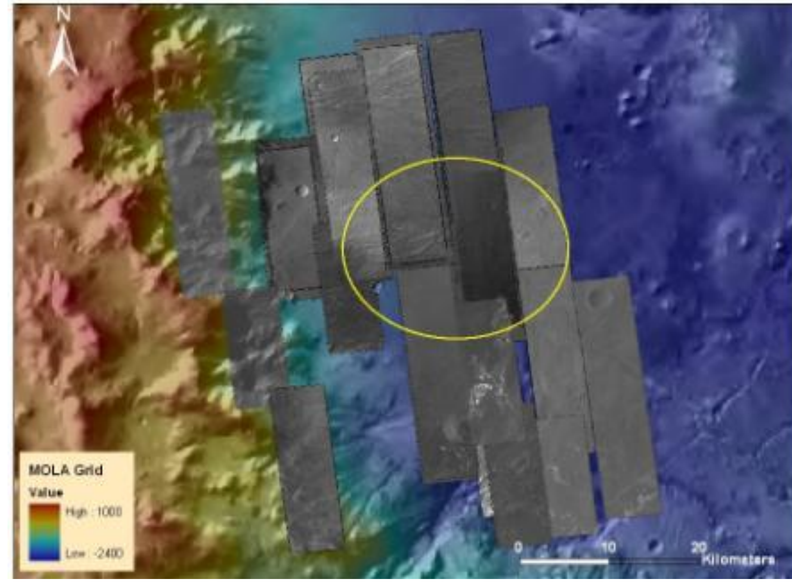
Ellipses Exact
Images Georeferenced

HiRISE Image Coverage in Ellipse

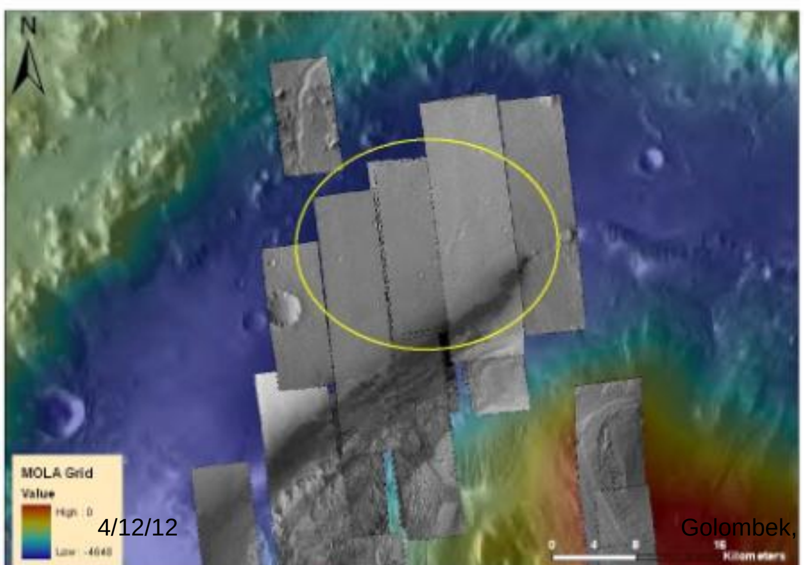
Eberswalde Crater HiRISE



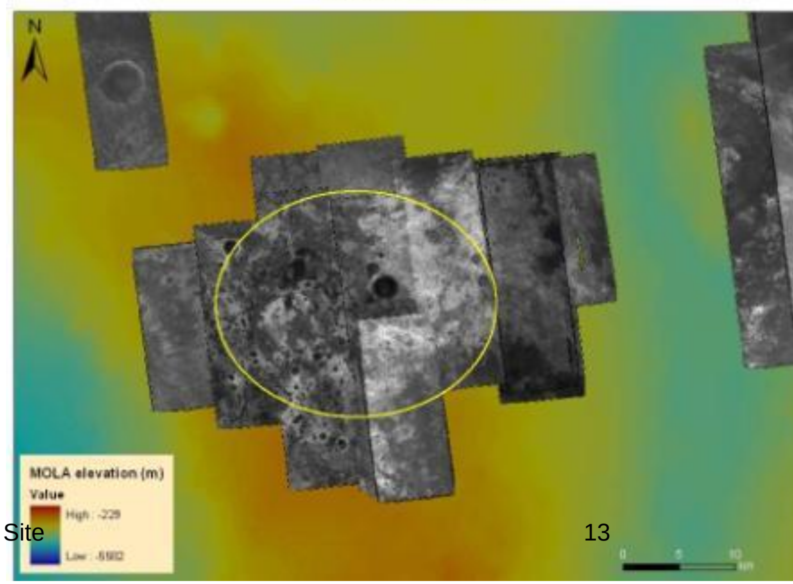
Holden Crater HiRISE



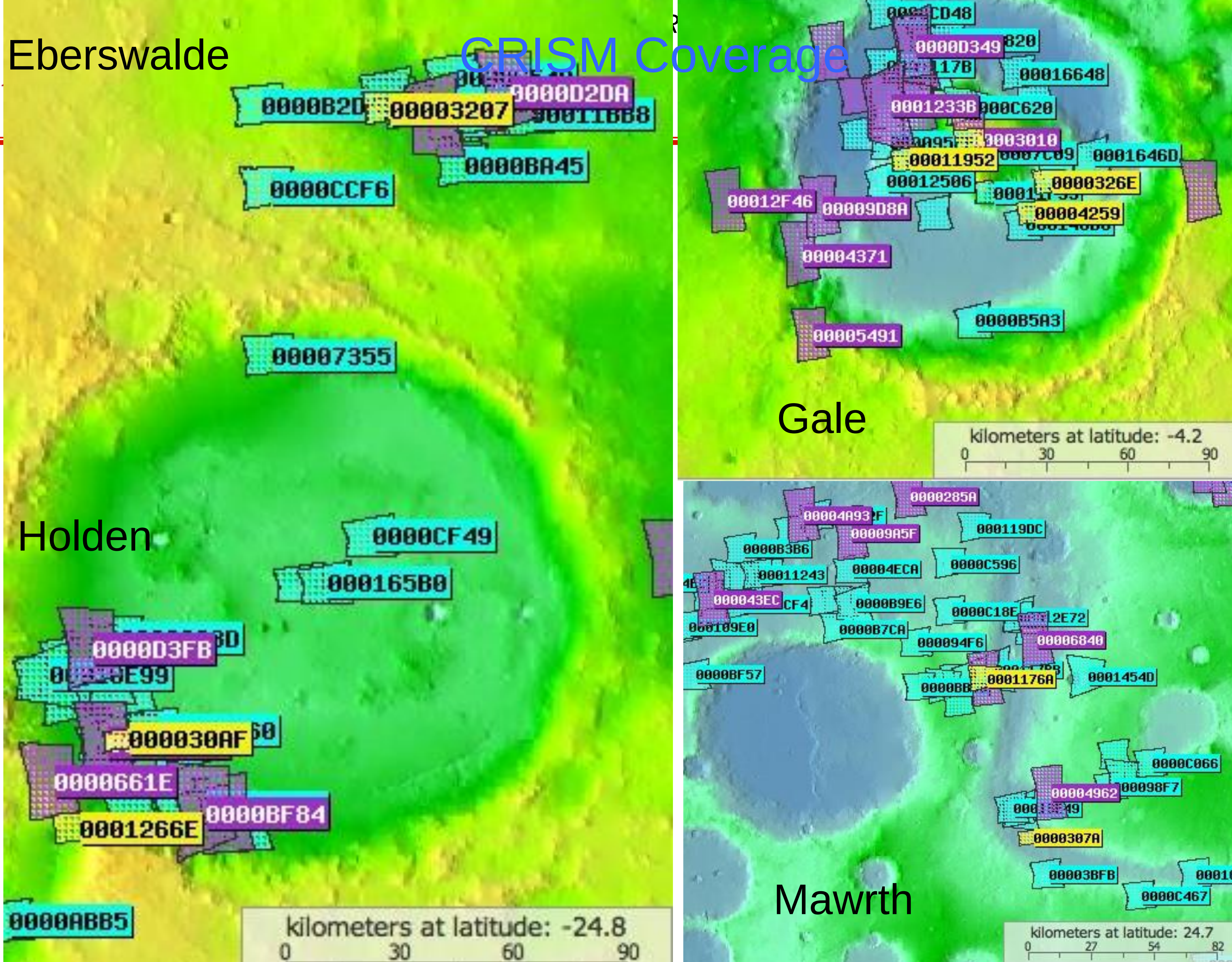
Gale Crater HiRISE



Mawrth Vallis HiRISE



CRISM Coverage



Mars Reconnaissance Orbiter

Gale Crater

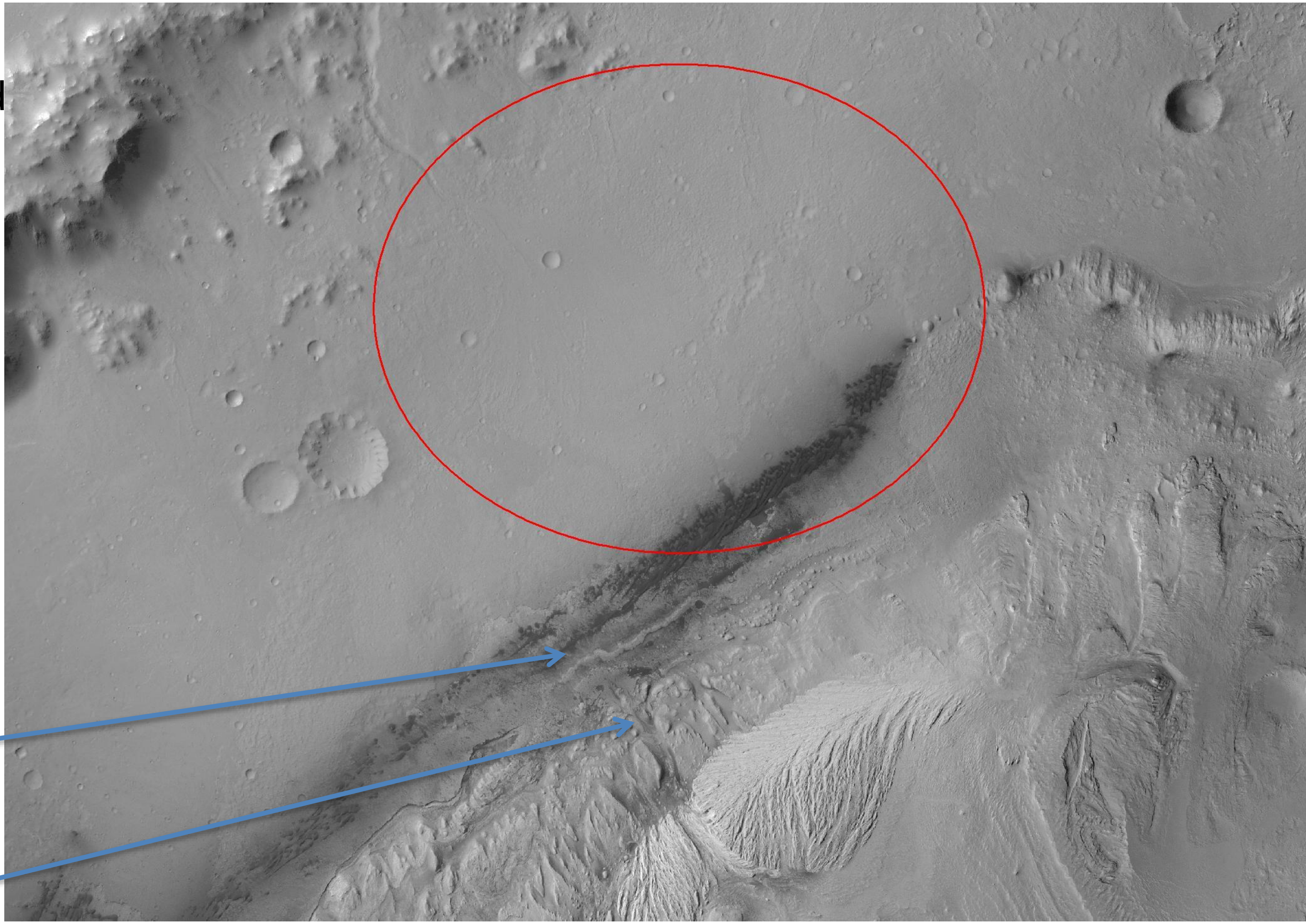
Land on Cratered Plains

Smooth, Flat, Cratered Plains

“Go To”

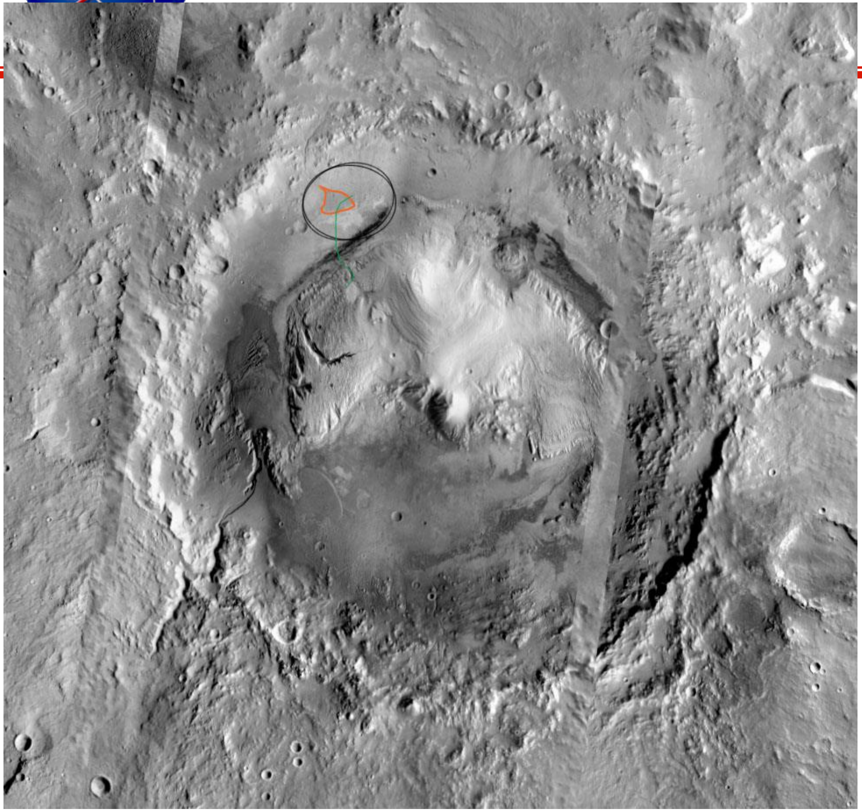
Sample Strata Here

Drive up Canyon Here

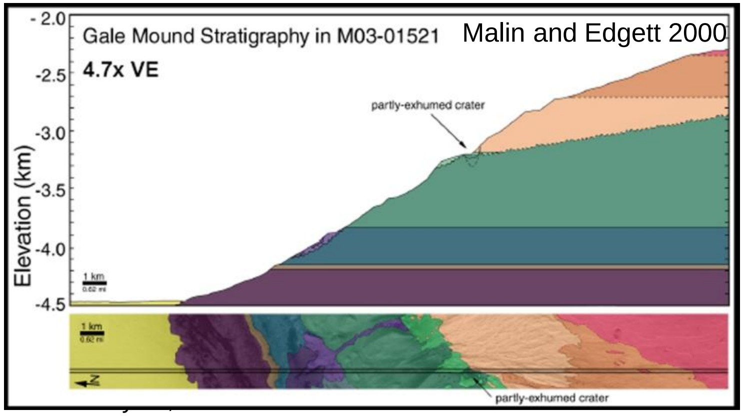


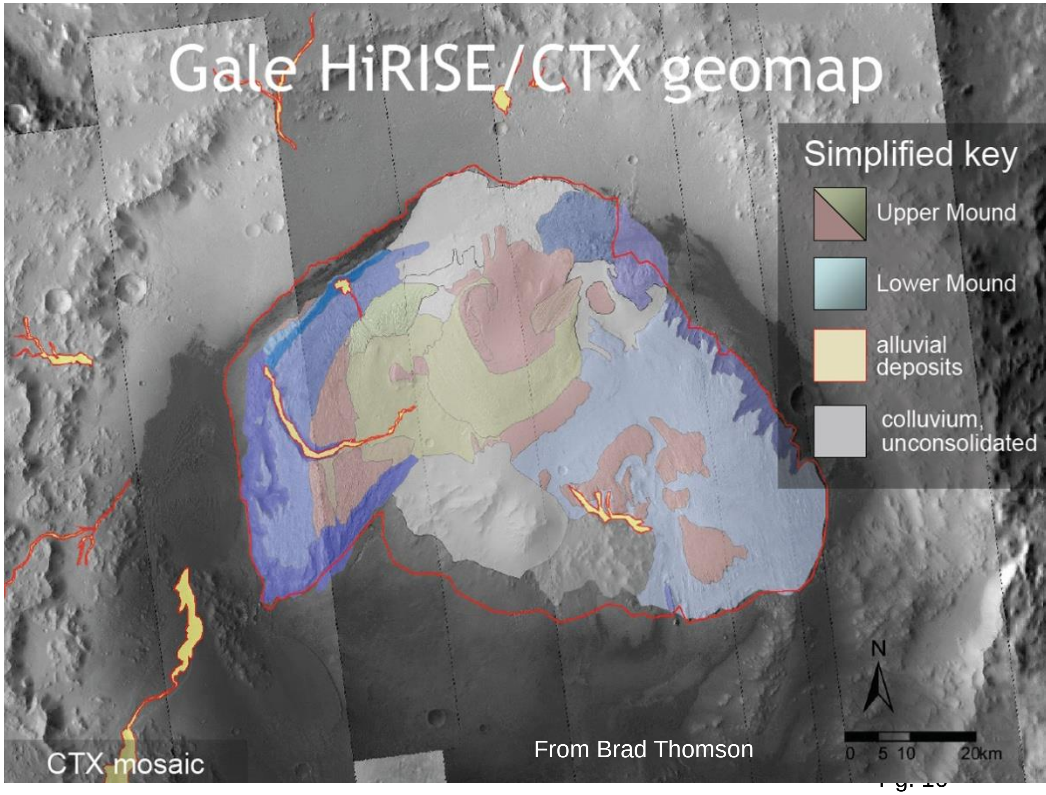
Mars Reconnaissance Orbiter

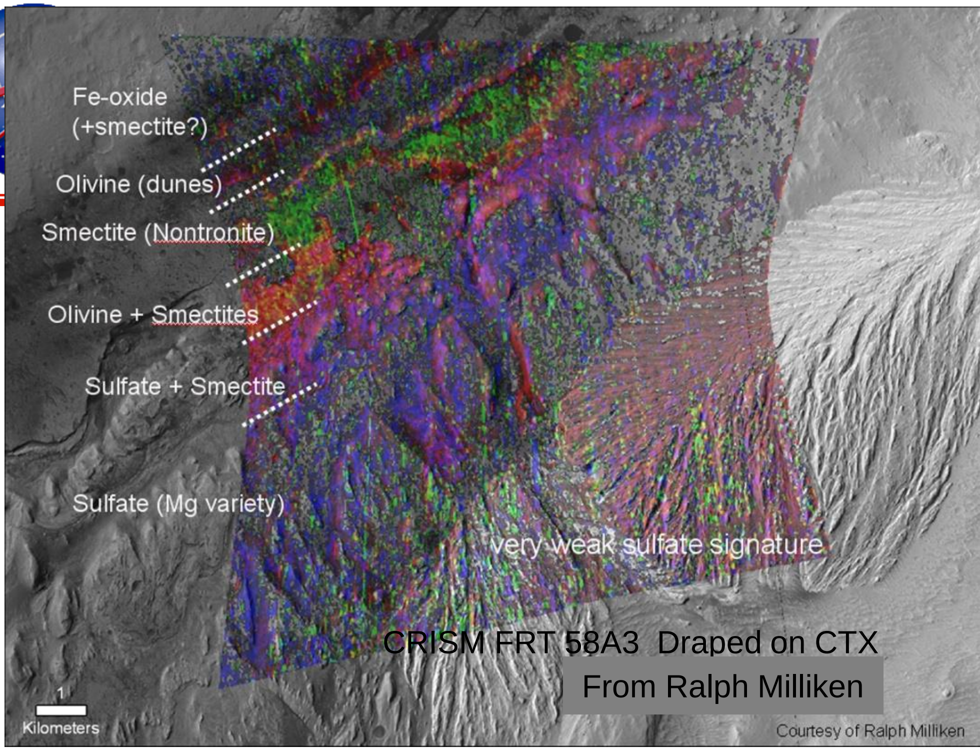
Gale Crater: K. Edgett, R. Anderson, J. Bell, D. Sumner, R. Milliken

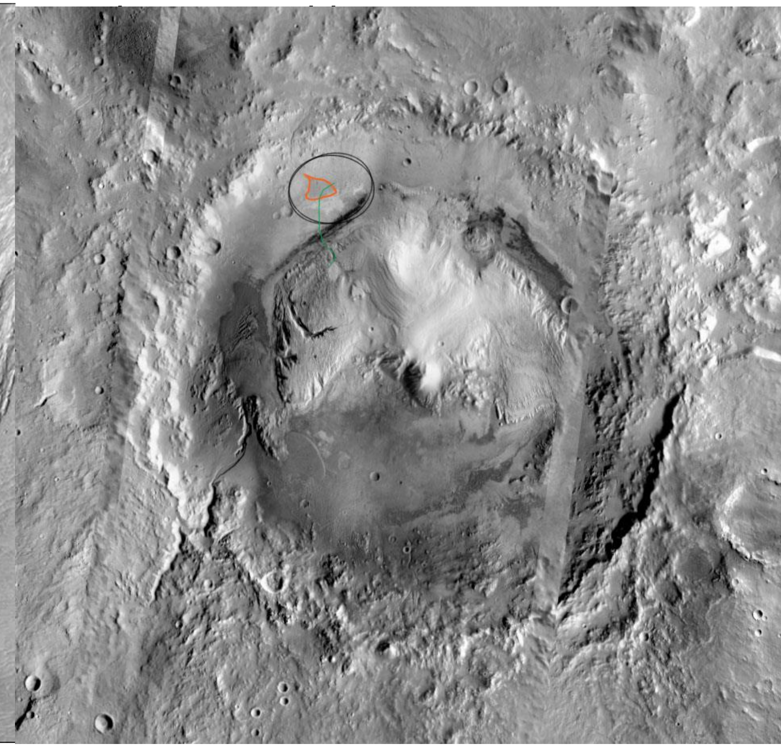


- **High diversity of geologic materials with different compositions and depositional conditions**
- **This diversity is arranged in a stratigraphic context**
- **Stratigraphy records multiple early Mars environments in sequential order**
- **Gale is characteristic of a family of craters that were filled, buried, and exhumed, providing insights into an important martian process**

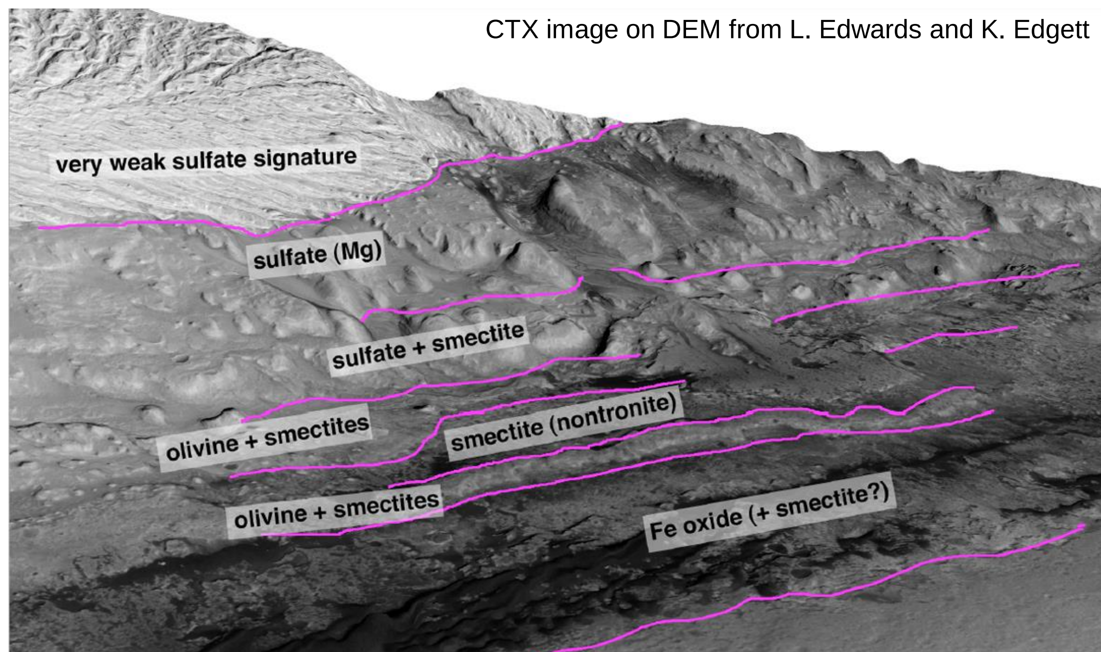








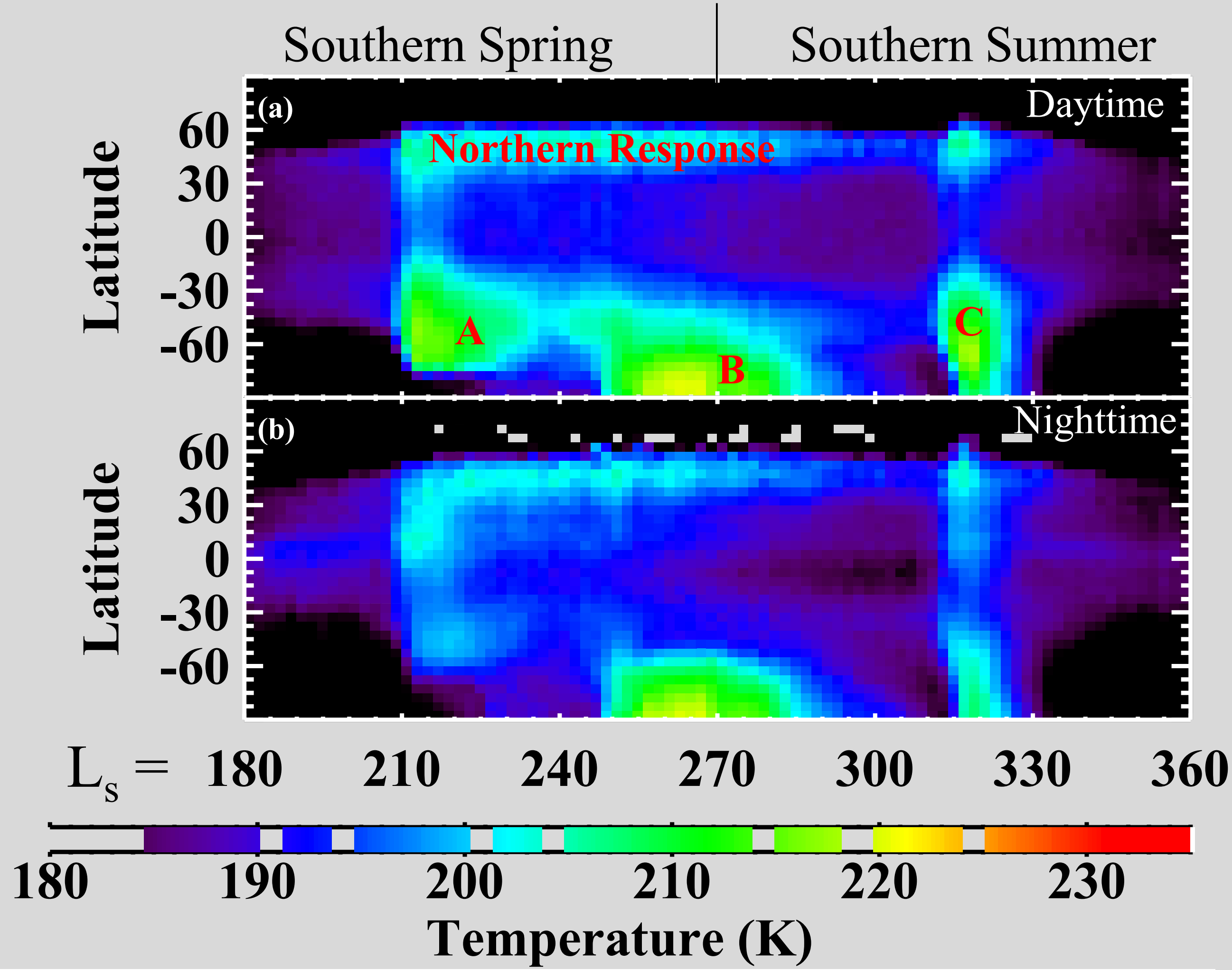
Gale Crater



CTX image on DEM from L. Edwards and K. Edgett

Three annually repeating periods of large dust events

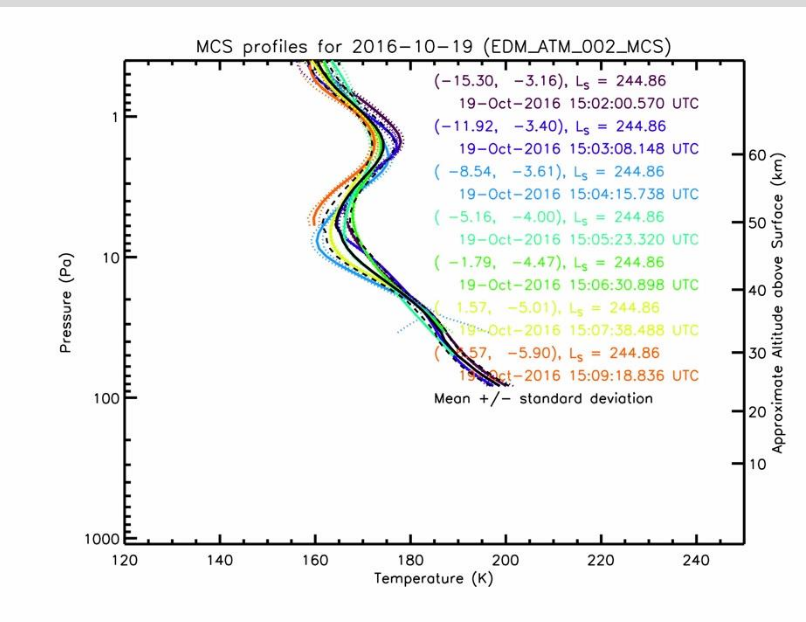
Zonal Mean Temperature at 50 Pa (~25 km)

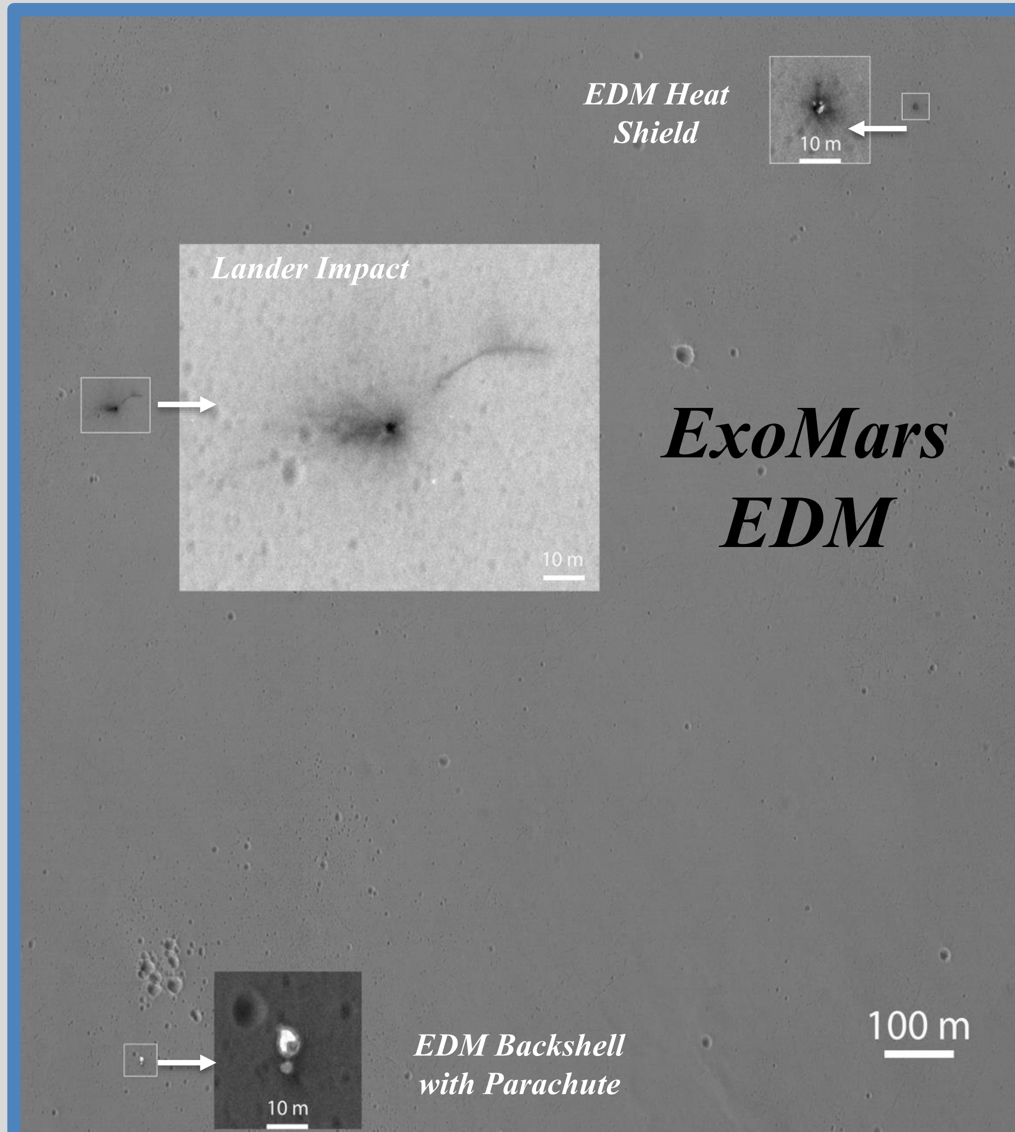


Reference: Kass, *et al.* (2016). Interannual similarity in the Martian atmosphere during the dust storm season, *Geophys. Res. Lett.*, 43, doi: 10.1002/2016GRL068978.

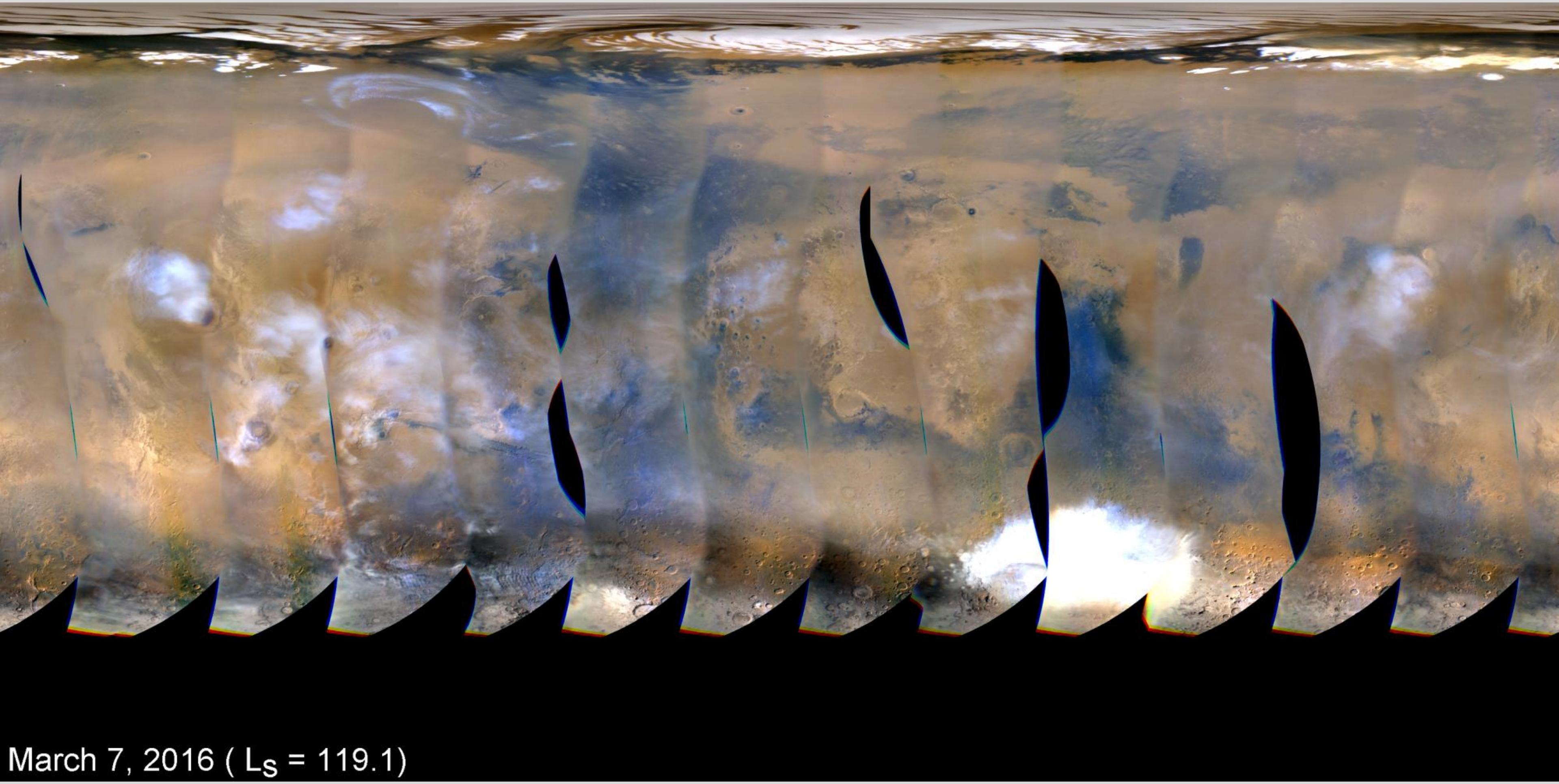
MRO Supports *ExoMars EDM*

- MCS Profiles the Atmosphere near EDM Entry;
- CTX finds the impact location post-landing;
- HiRISE resolves the EDM flight elements: Lander, Back-shell, Heat Shield.





Recent MARCI global weather map



Mission Overview

LAUNCH

- Atlas V 541 vehicle
- Launch Readiness Date: July 2020
- Launch window: July/August 2020

CRUISE/APPROACH

- ~7 month cruise
- Arrive Feb 2021

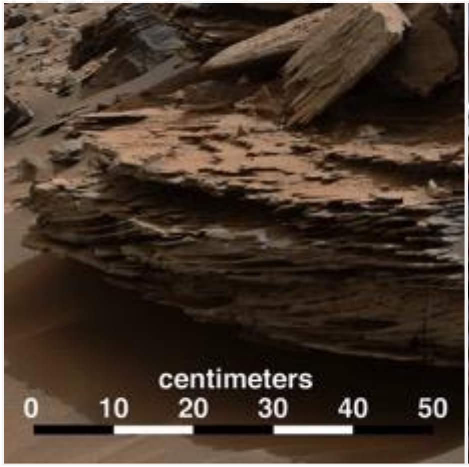
ENTRY, DESCENT & LANDING

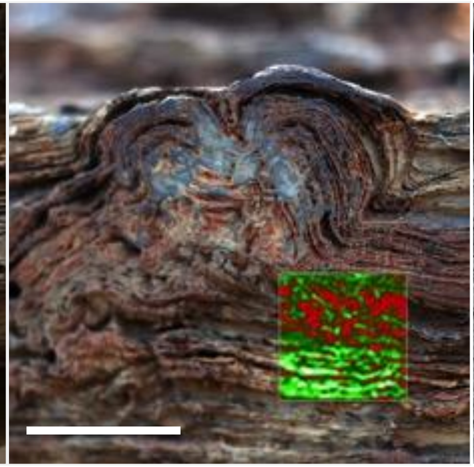
- MSL EDL system (+ Range Trigger and Terrain Relative Navigation): guided entry and powered descent/Sky Crane
- 16 x 14 km landing ellipse (range trigger baselined)
- Access to landing sites ±30° latitude, ≤ -0.5 km elevation
- Curiosity-class Rover

SURFACE MISSION

- 20 km traverse distance capability
- Enhanced surface productivity
- Qualified to 1.5 Martian year lifetime
- Seeking signs of past life
- Returnable cache of samples
- Prepare for human exploration of Mars

Mars 2020 Mission Objectives





GEOLOGIC EXPLORATION

- Explore an ancient environment on Mars
- Understand processes of formation and alteration

HABITABILITY AND BIOSIGNATURES

- Assess habitability of ancient environment
- Seek evidence of past life
- Select sampling locations with high biosignature preservation potential

PREPARE A RETURNABLE CACHE

- Capability to collect ~40 samples and blanks, 20 in prime mission
- Include geologic diversity
- Deposit samples on the surface for possible return

PREPARE FOR HUMAN EXPLORATION

- Measure temperature, humidity, wind, and dust environment
- Demonstrate In Situ Resource Utilization by converting atmospheric CO_2 to O_2

Curiosity science payload

Jet Propulsion Laboratory
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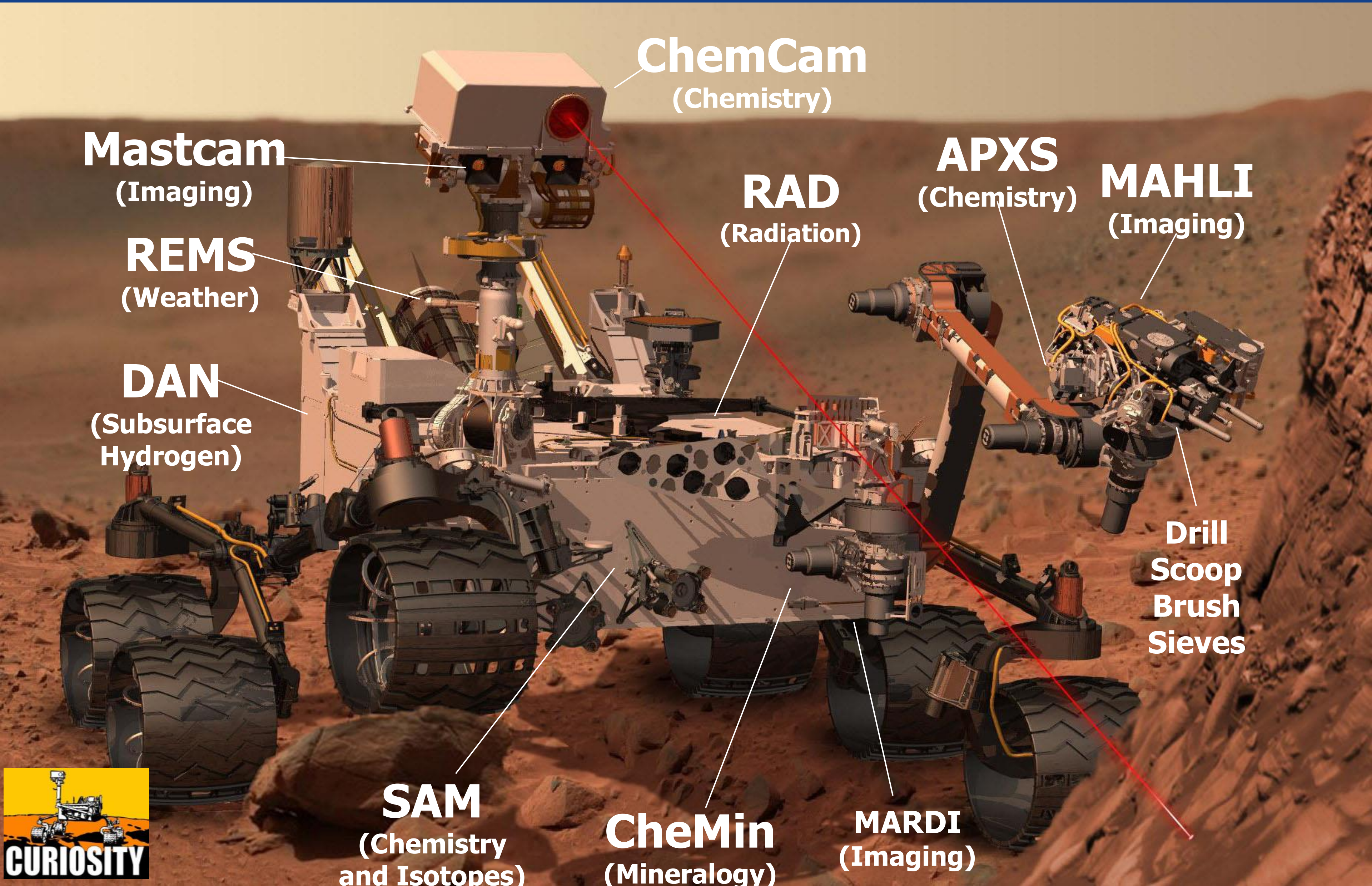
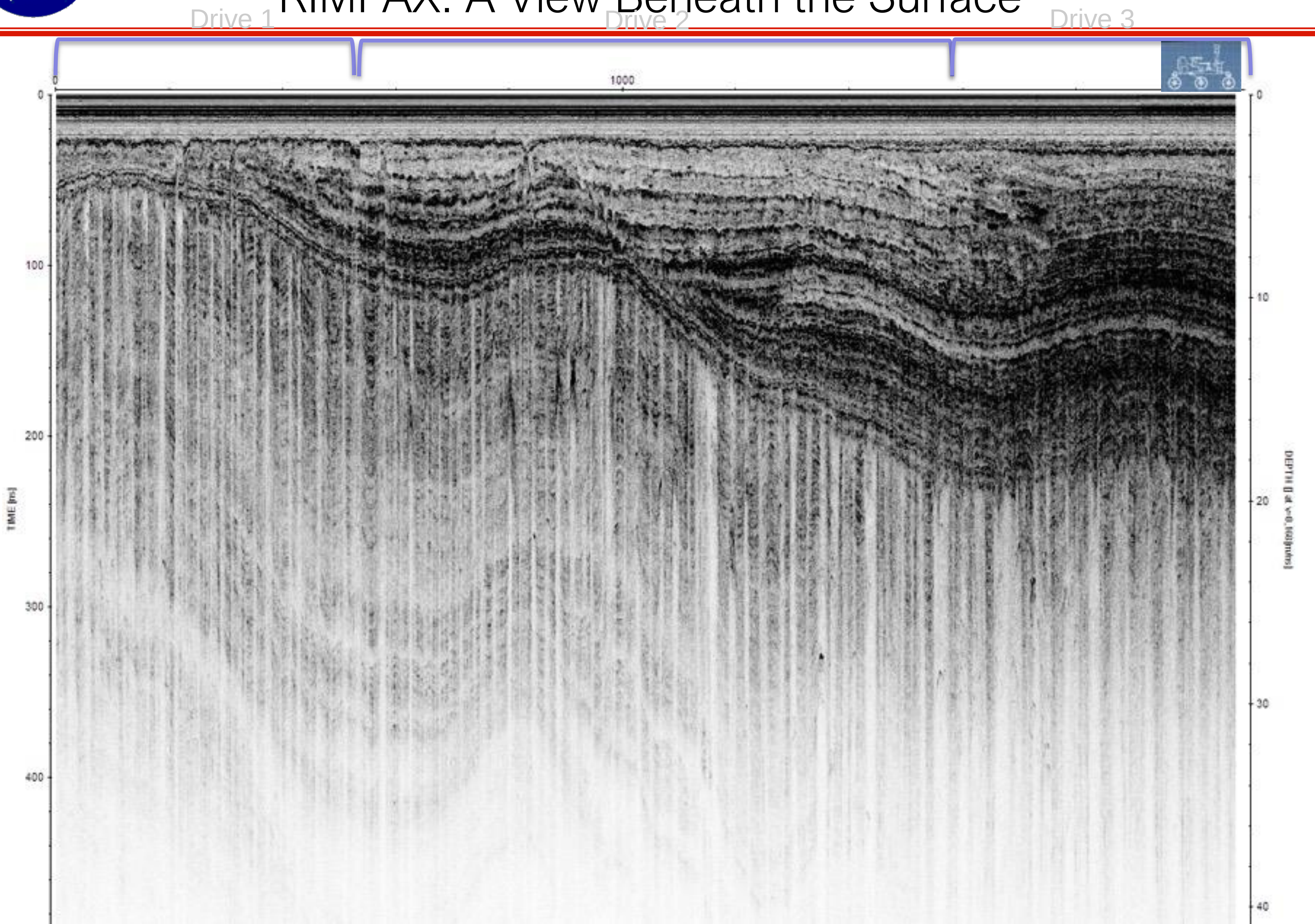


Mastcam-Z

A Geologic, Stereoscopic, and Multispectral Investigation for the NASA Mars-2020 Rover Mission

improved stereo **zoom** camera

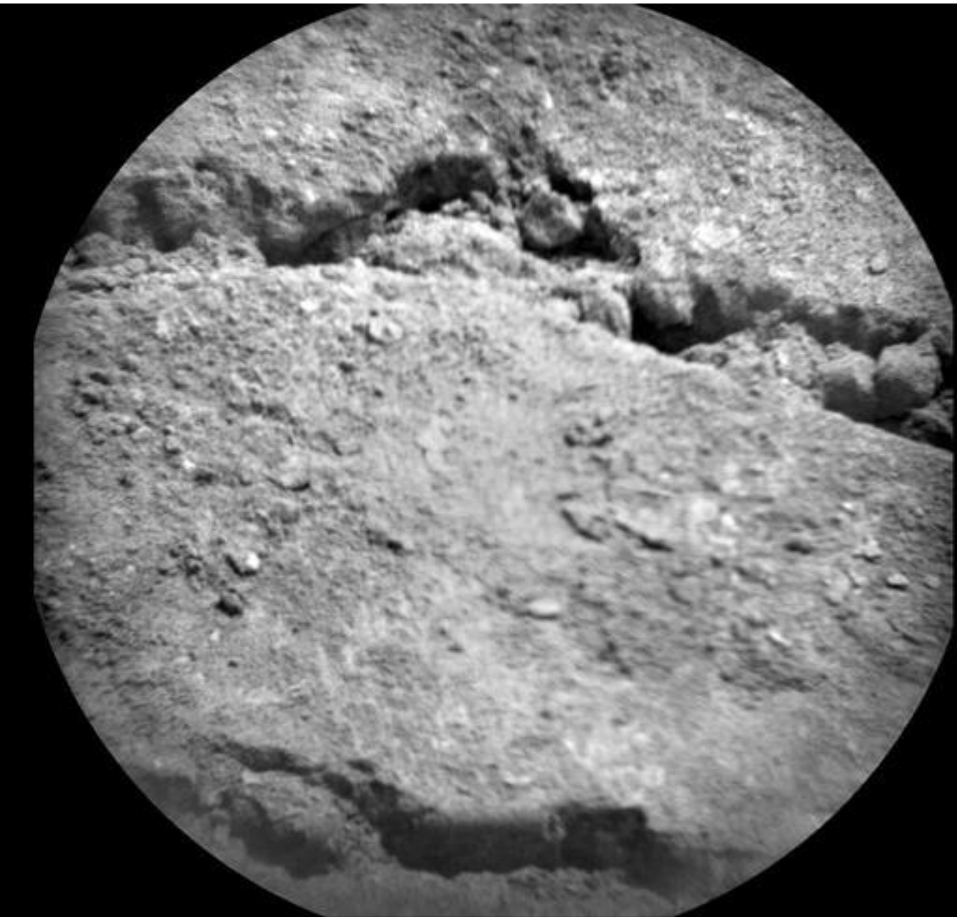
RIMFAX: A View Beneath the Surface



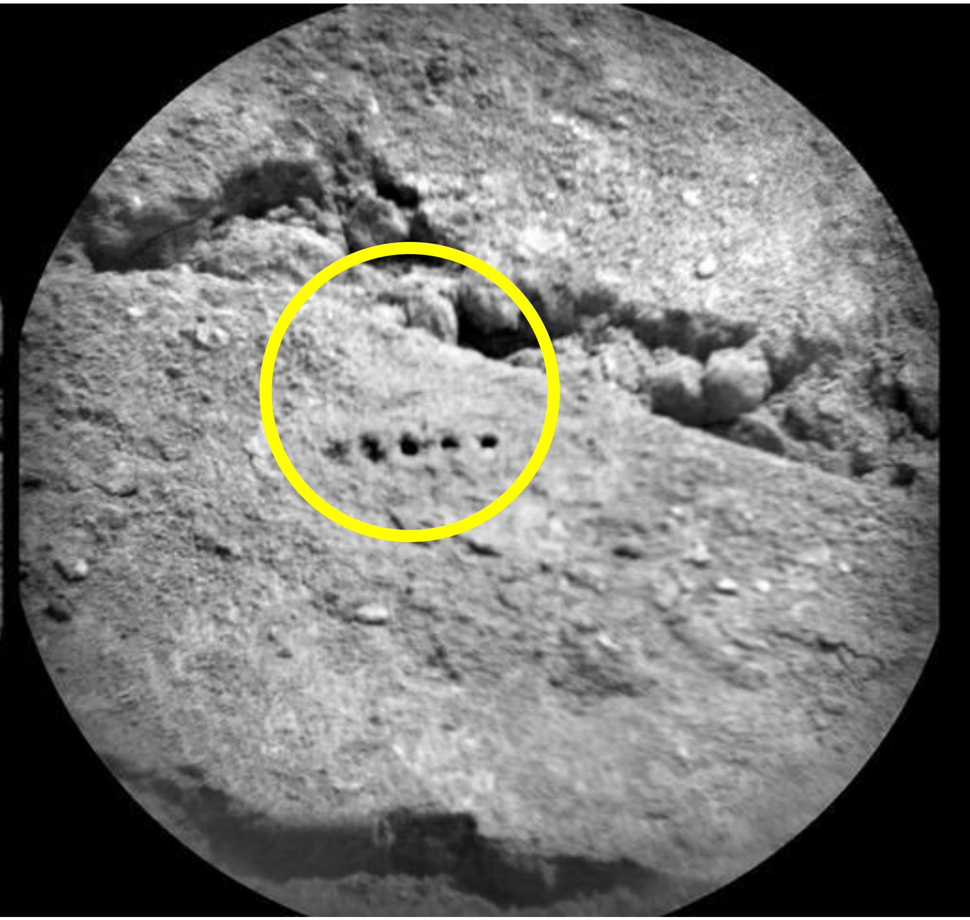
Mars Reconnaissance Orbiter

SuperCam: Enhanced ChemCam

Before

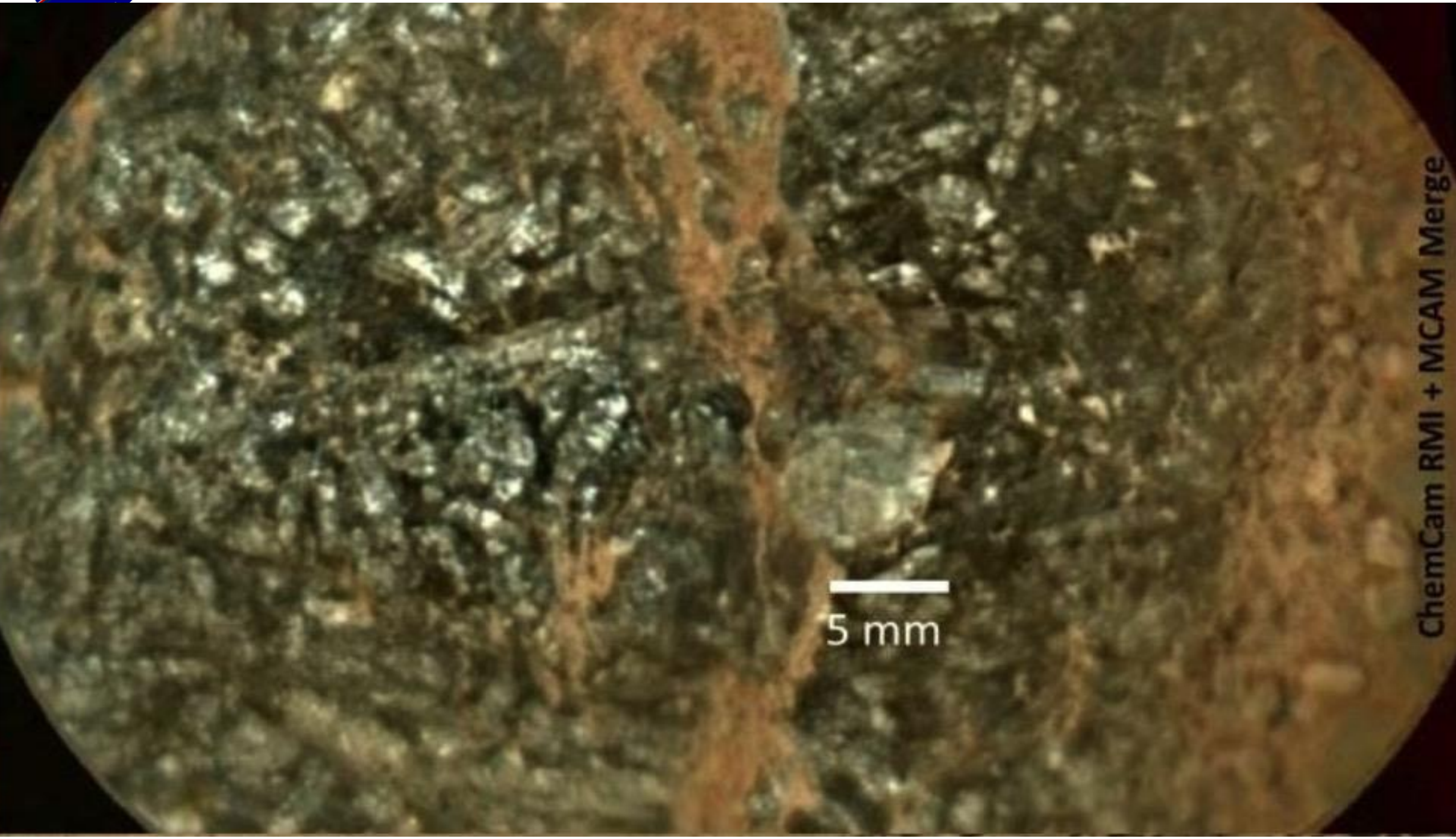


After



ChemCam Target: Beechey (Sol 19)
Power: 1 Gigawatt
5-spot raster, shots per spot: 50

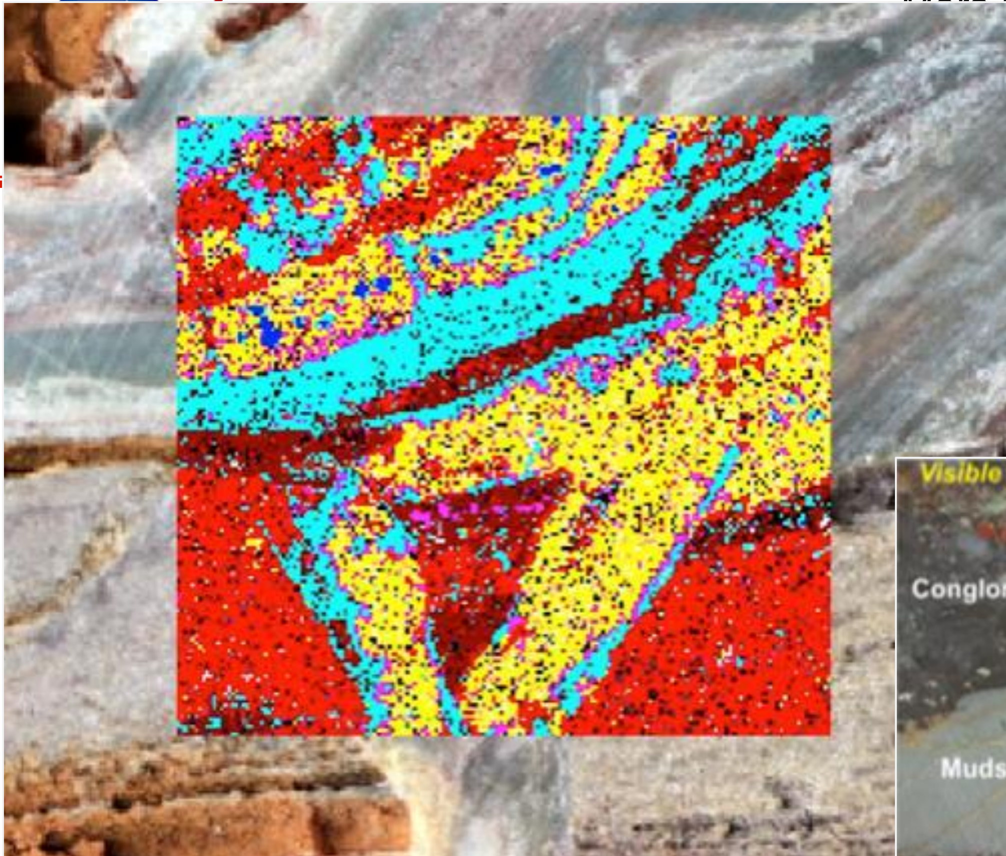
Color RMI, LIBS, Raman, VISIR

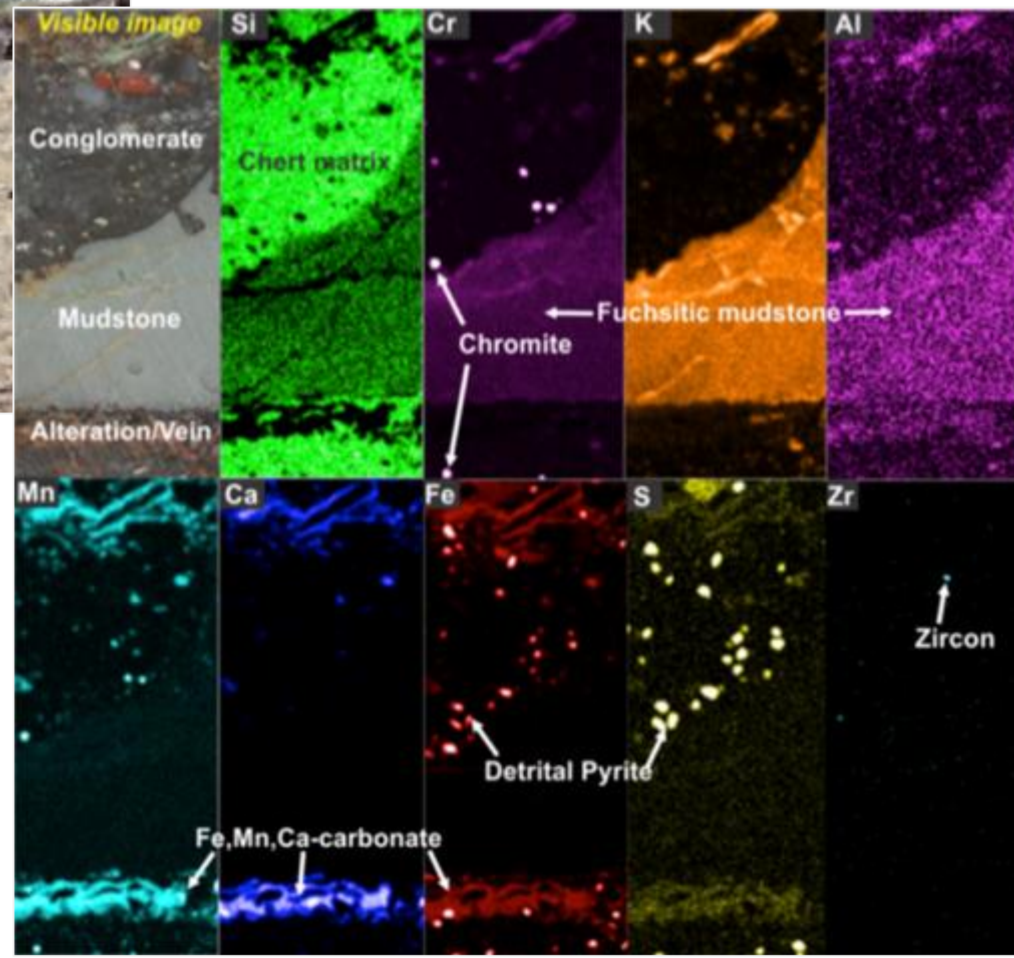



2 mm


WATSON

PIXL: Planetary Instrument For X-ray Lithochemistry





micro x-ray fluorescence for elemental mapping with sub-mm resolution

National Aeronautics and Space Administration
Jet Propulsion Laboratory
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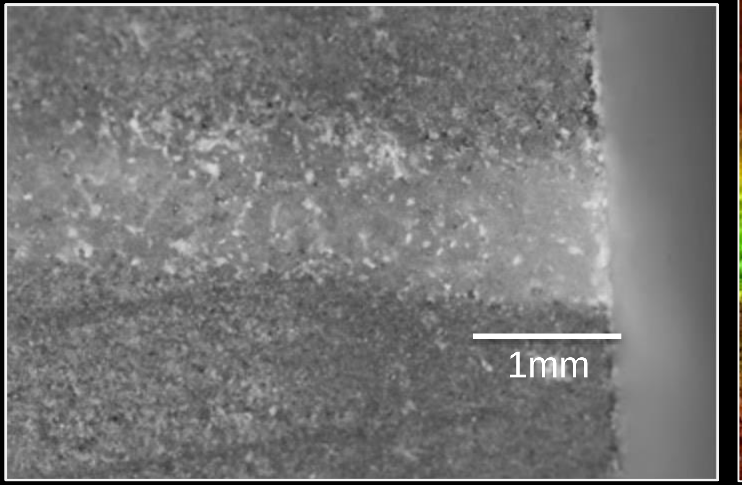
Mars Reconnaissance Orbiter

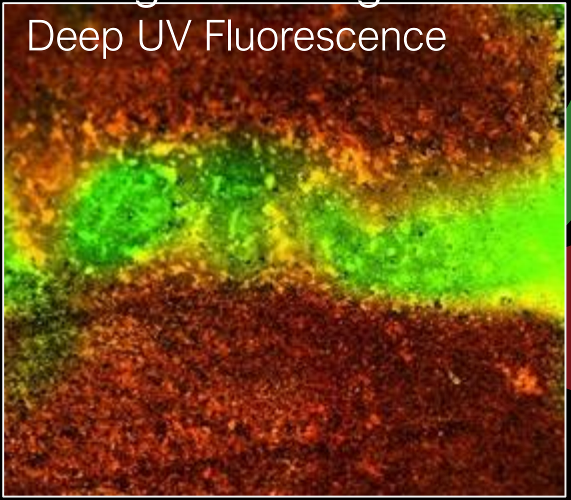
SHERLOC: Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals

SHERLOC's view through WATSON

High Resolution Camera



Organic Image

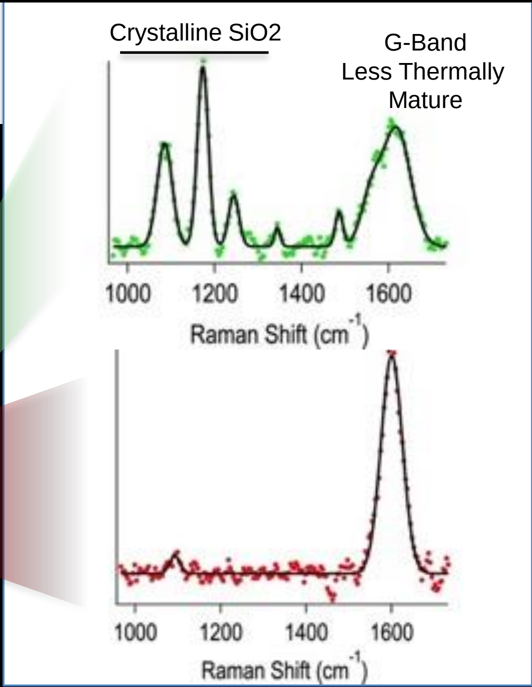


More Mature Less Mature

Organic Maturity

Organic & Mineral Analyzer

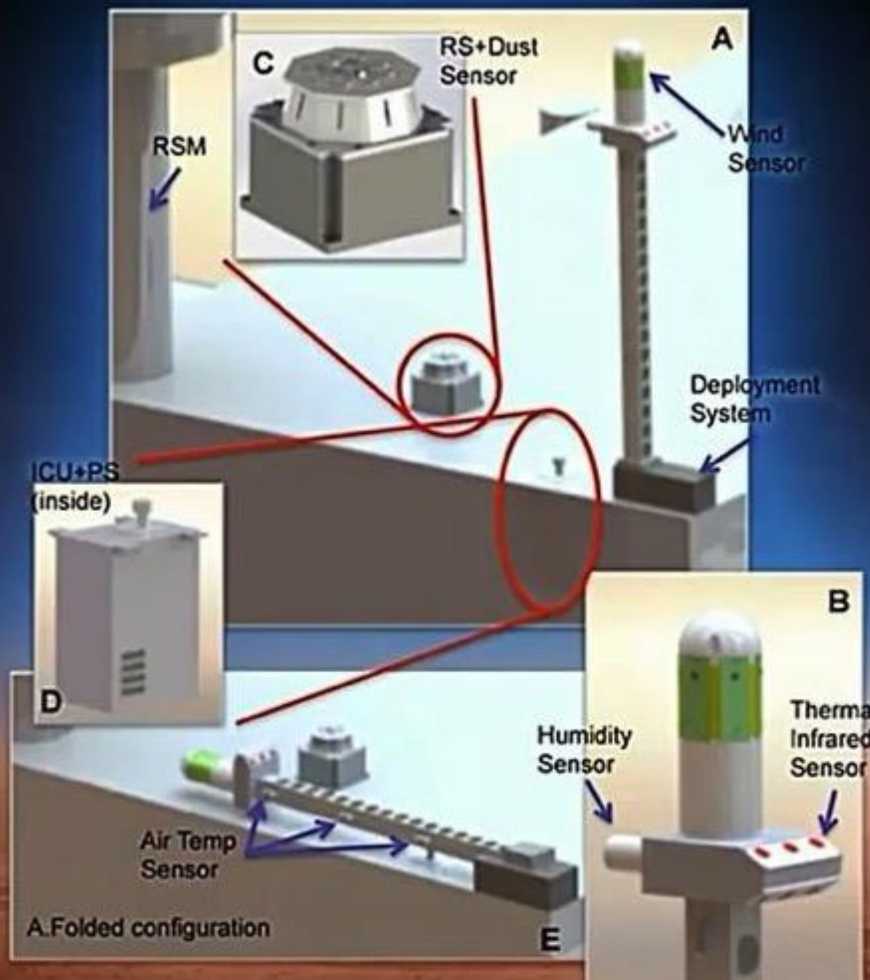
Deep UV Raman



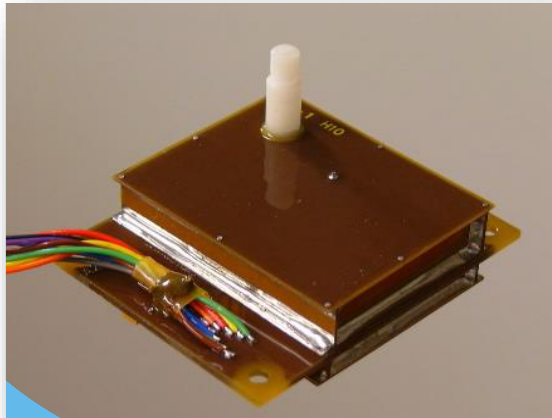
MEDA

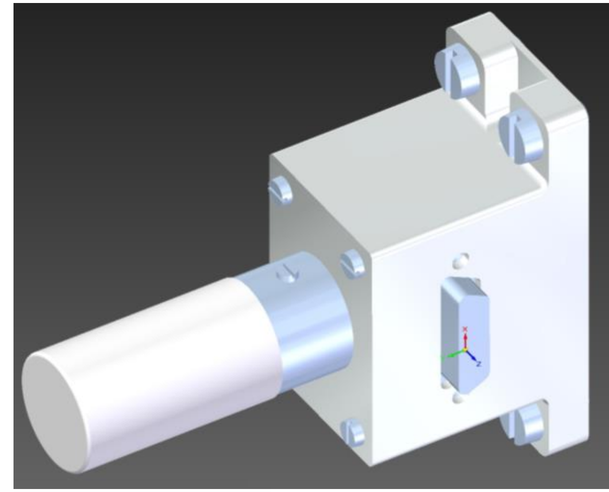
Mars Environmental Dynamics Analyzer

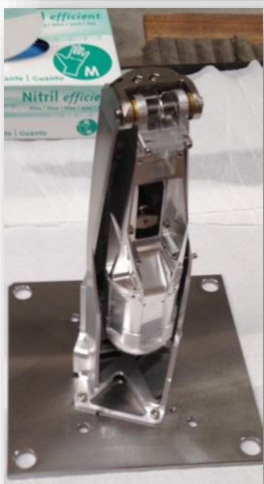
temperature, humidity, wind, dust analyzer

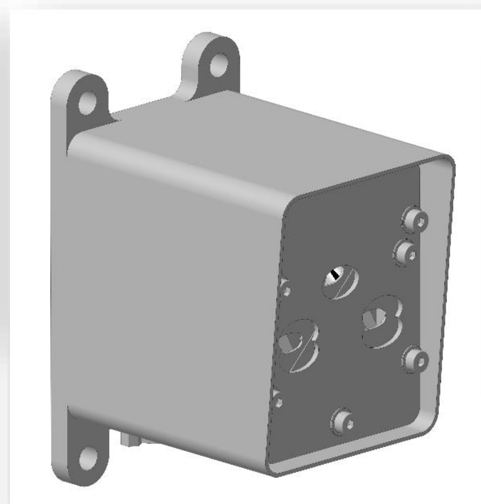


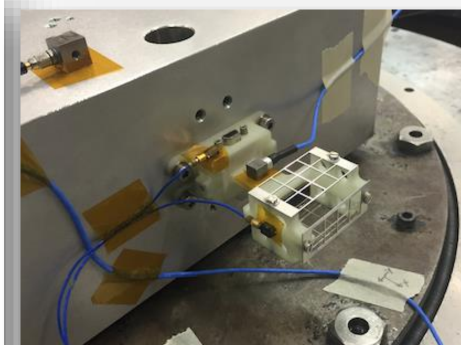
MEDA subsystems



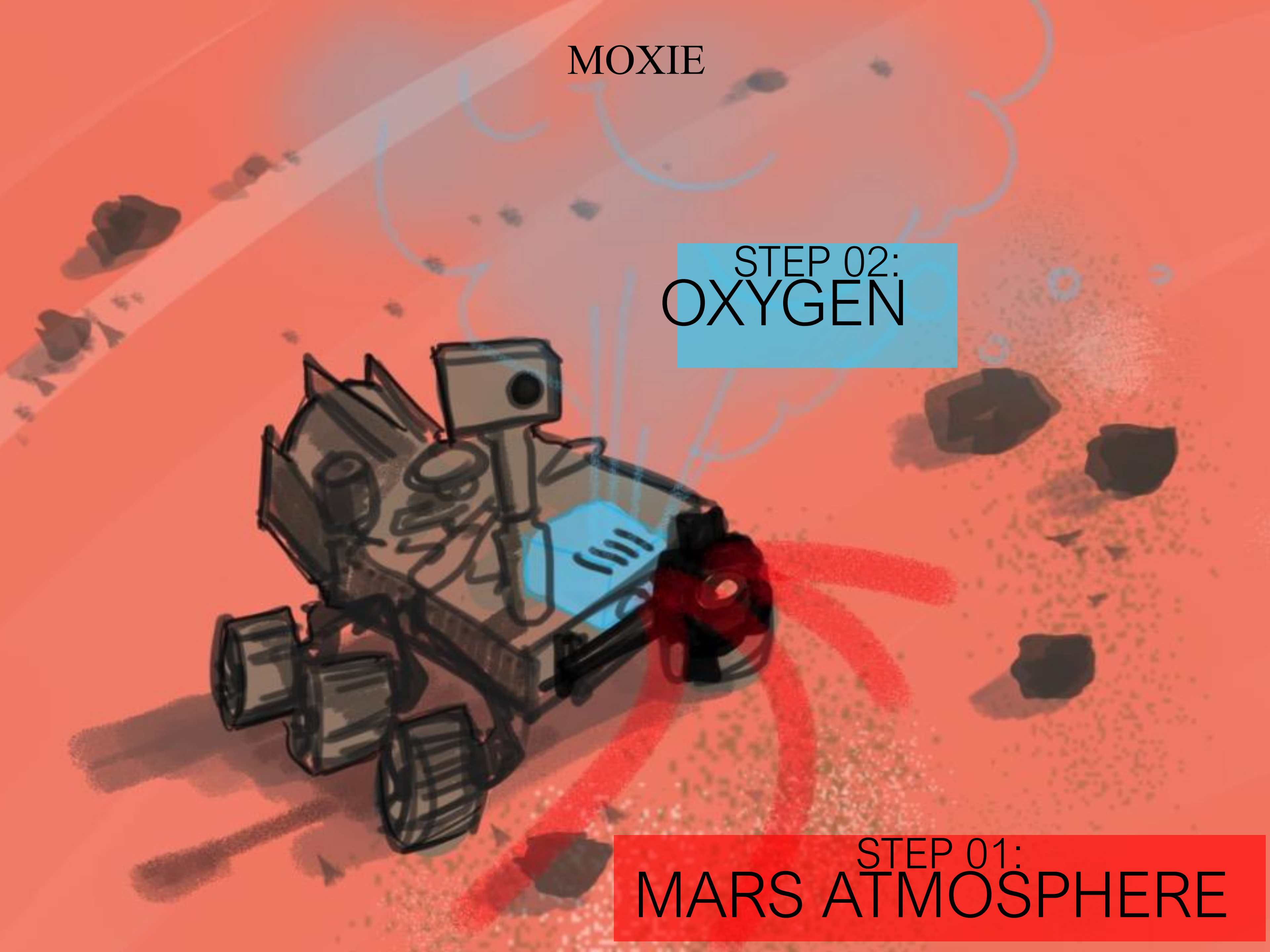








MOXIE



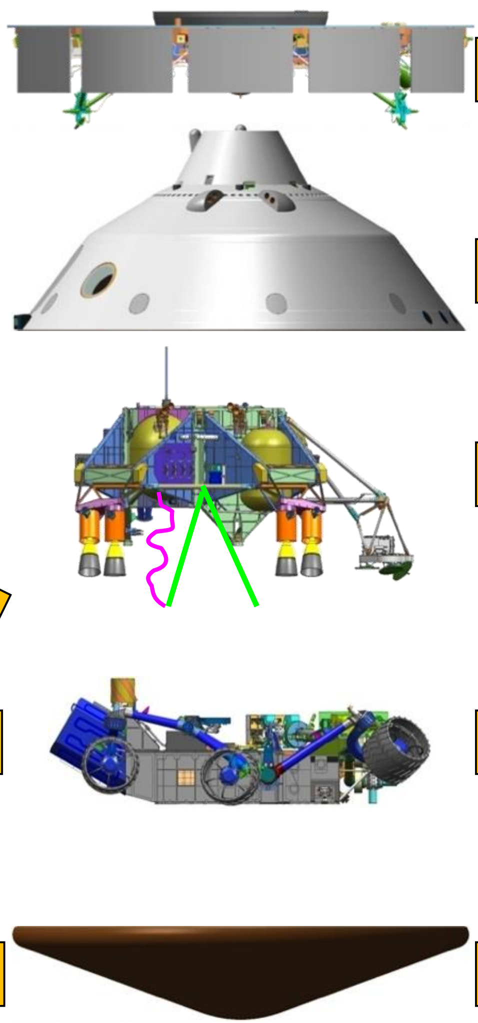
Spacecraft Build Approach

Launch Vehicle
- KSC/Launch Services Program procurement

MMRTG
- DoE procurement to industry

Science & Exploration Technology Investigations
- Source per proposals via AO selection

MEDLI2
- NASA Centers (LaRC, ARC, and JPL)



- Built in-house at JPL
- Lowest cost and risk per make-buy study and industry RFIs

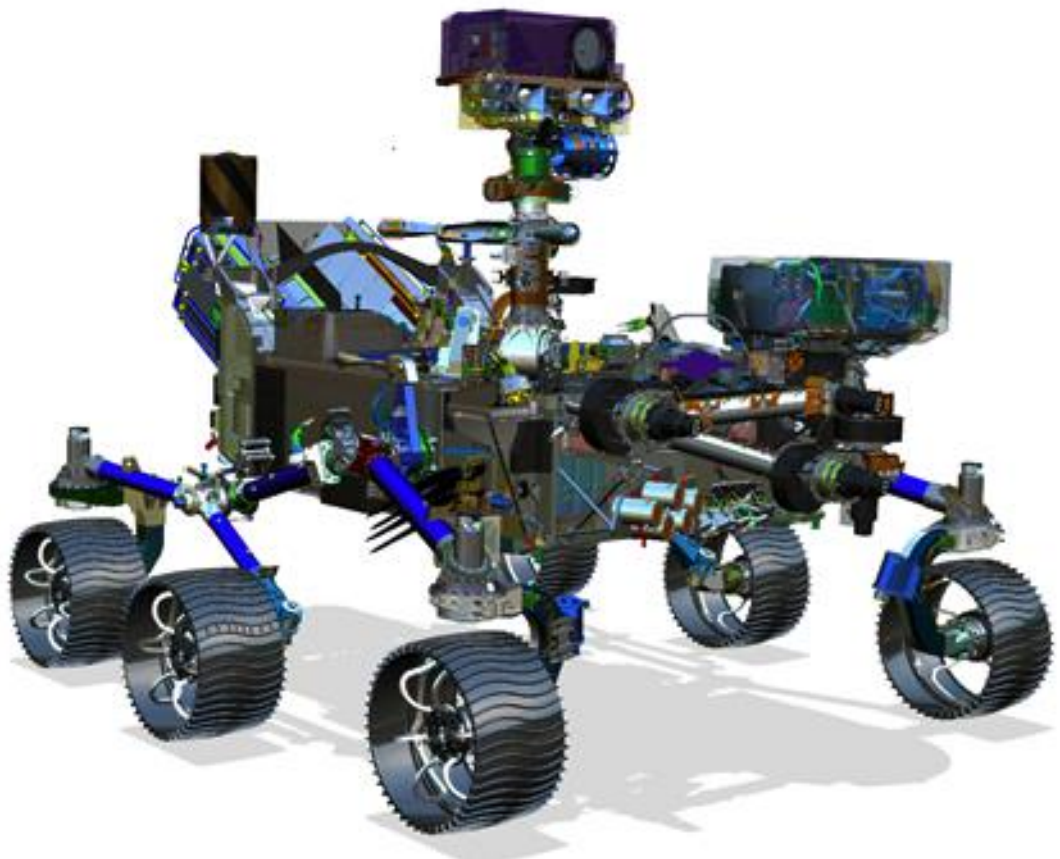
- Built by Lockheed-Martin/Denver
- Procure as sole source—most cost effective

- Built in-house at JPL
- Major industry subcontracts/components
- Rebuild in-house due to criticality of EDL and rover interface

- Built in-house at JPL
- Major industry subcontracts/components
- Spanish contributed High Gain Antenna
- Rebuild in-house due to complexity of vehicle, residual hardware, criticality of EDL and rover interface, operations experience

- Built by Lockheed-Martin/Denver
- Procure as sole source—most cost effective

Mars 2020 Rover Concept



High Heritage from MSL

- Avionics
- Power
- GN&C
- Telecom
- Thermal
- Mobility

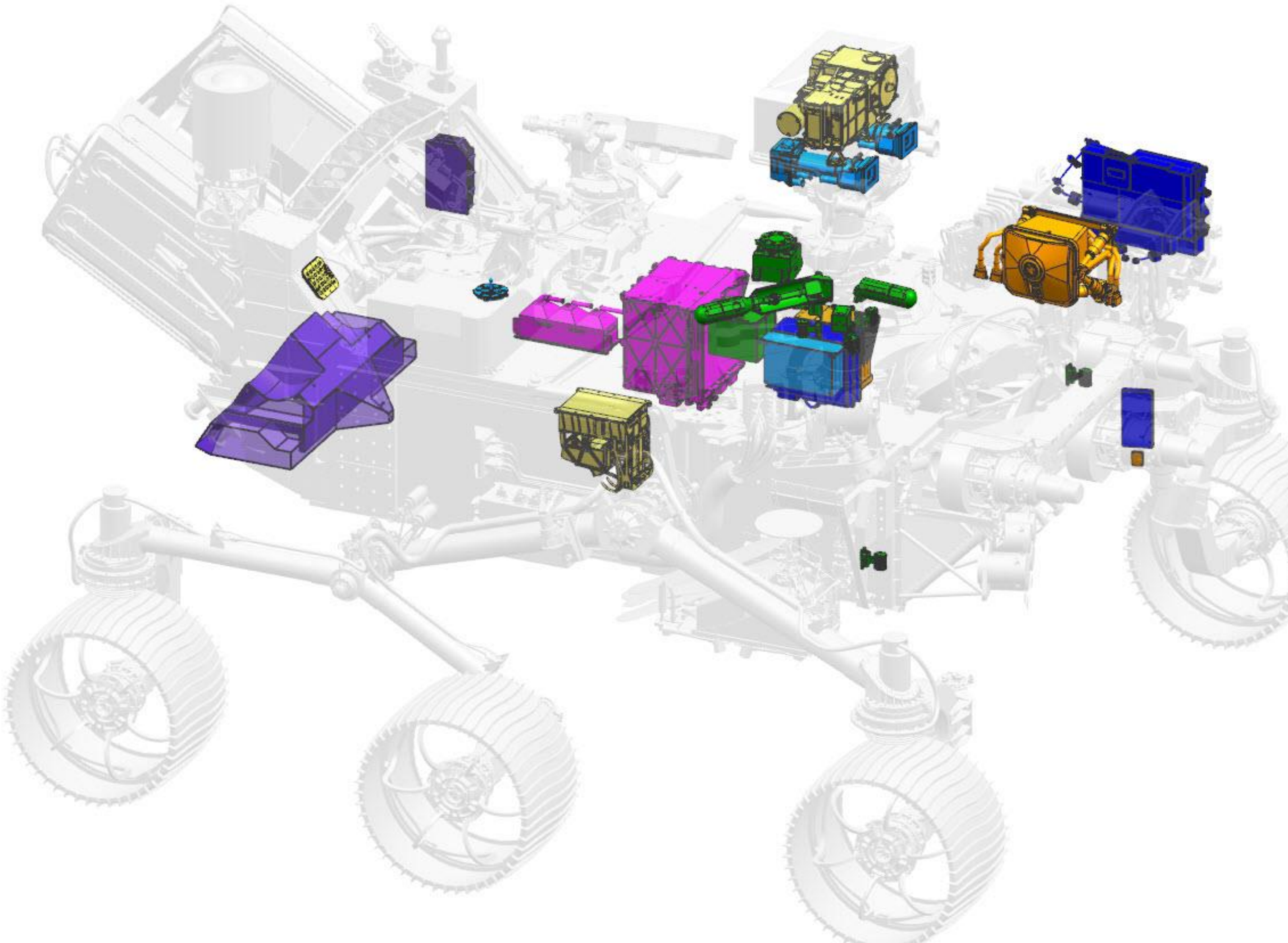
Changed

- New Science Instrument Suite
- New Sampling Caching System
- Modified Chassis
- Modified Rover Harness
- Modified Surface FSW
- Modified Rover Motor Controller
- Modified Wheels

Mars 2020 Mission Objectives

- **Conduct Rigorous *In Situ* Science**
  - **A. Geologic Context and History** Carry out an integrated set of context, contact, and spatially-coordinated measurements to characterize the geology of the landing site
  - **B. In Situ Astrobiology** Using the geologic context as a foundation, find and characterize **ancient** habitable environments, identify rocks with the highest chance of preserving **signs** of **ancient** Martian life if it were present, and within those environments, seek the signs of life
- **Enable the Future**
  - **C. Sample Return** Assemble rigorously documented and returnable cached samples for possible return to Earth
  - **D. Human Exploration** Facilitate future human exploration by making significant progress towards filling major strategic knowledge gaps and…
  - **Technology** …demonstrate technology required for future Mars exploration
- **Execute Within Current Financial Realities**
  - – Utilize MSL-heritage design and a moderate instrument suite to stay within the resource constraints specified by NASA

Mars 2020 Payload Family Picture



Instrument Key

Mastcam-Z
Stereo Imager

MEDA
Mars Environmental Measurement

MOXIE
In-Situ Oxygen Production

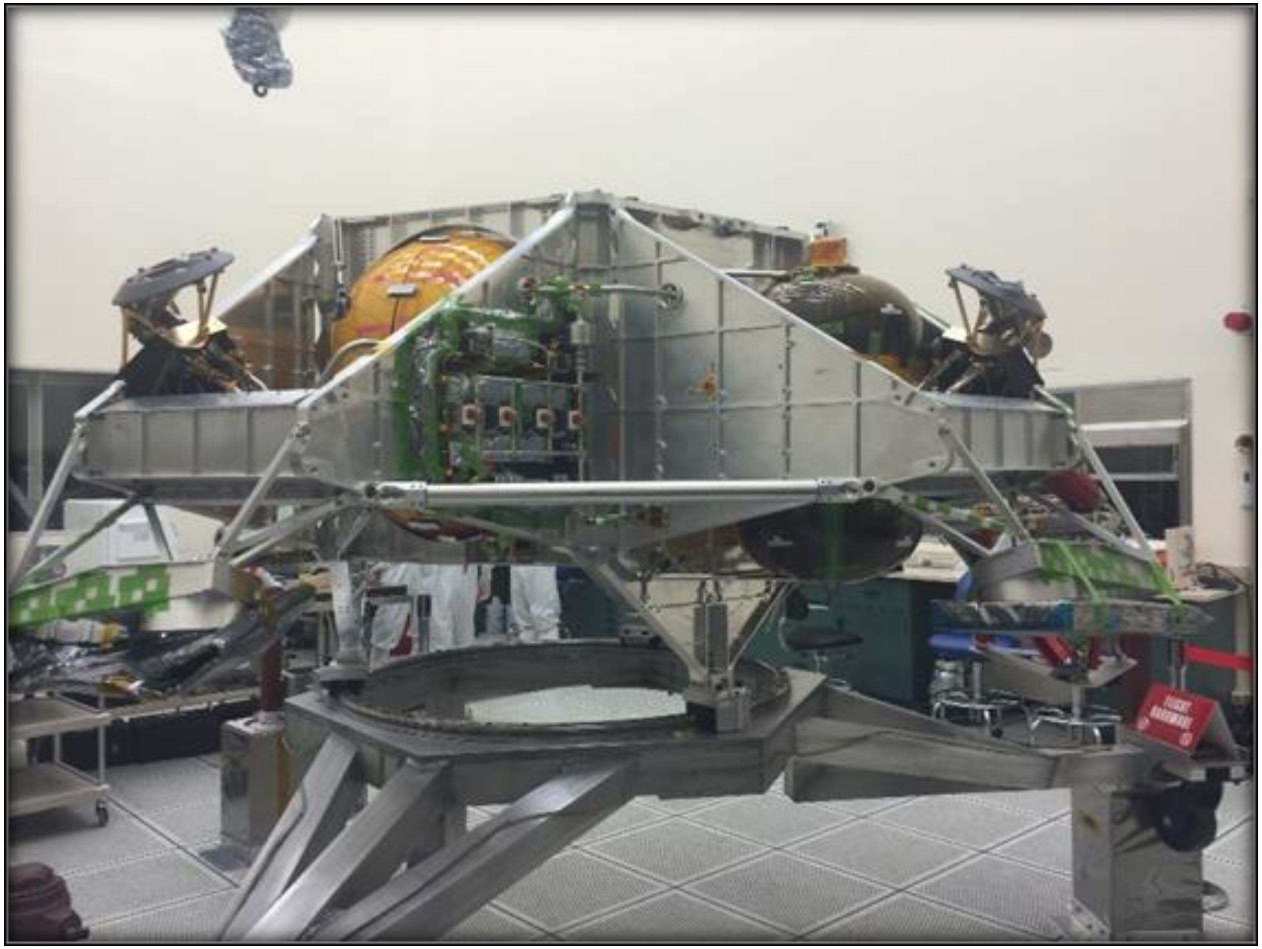
PIXL
Microfocus X-ray fluorescence spectrometer

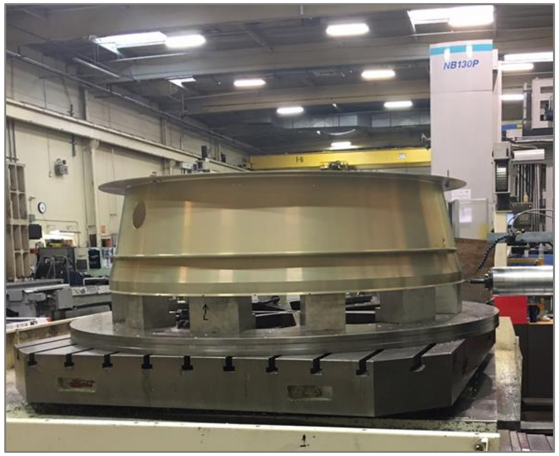
RIMFAX
Ground Penetrating Radar

SHERLOC
Fluorescence and Raman spectrometer and Visible context imaging

SuperCam
LIBS and Raman

Cruise / EDL Systems – In Assembly

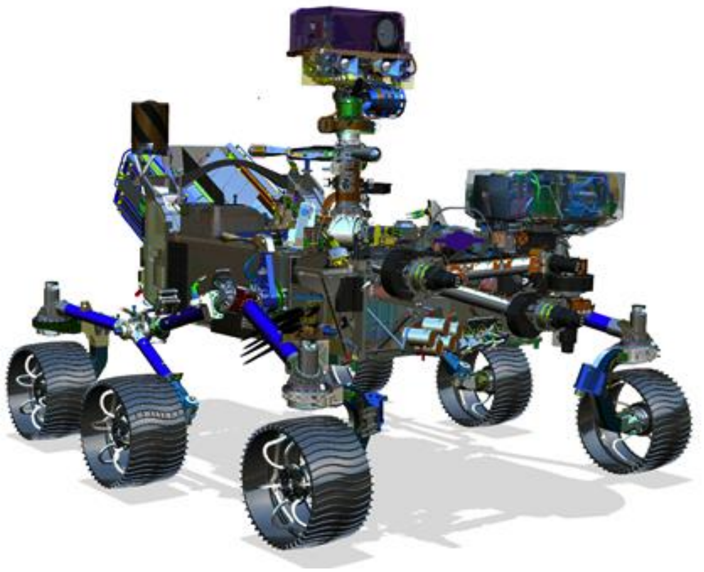




Project Overview

Salient Features

- *Category: 1*
- *Risk Class: A-tailored*
- *Directed, JPL in-house implementation*
- *High heritage MSL design*
- *Modifications only as necessary to accommodate new payload and Sampling / Caching System (SCS)*
- *Planetary Protection Category V Restricted Earth Return per Level 1 Requirements*



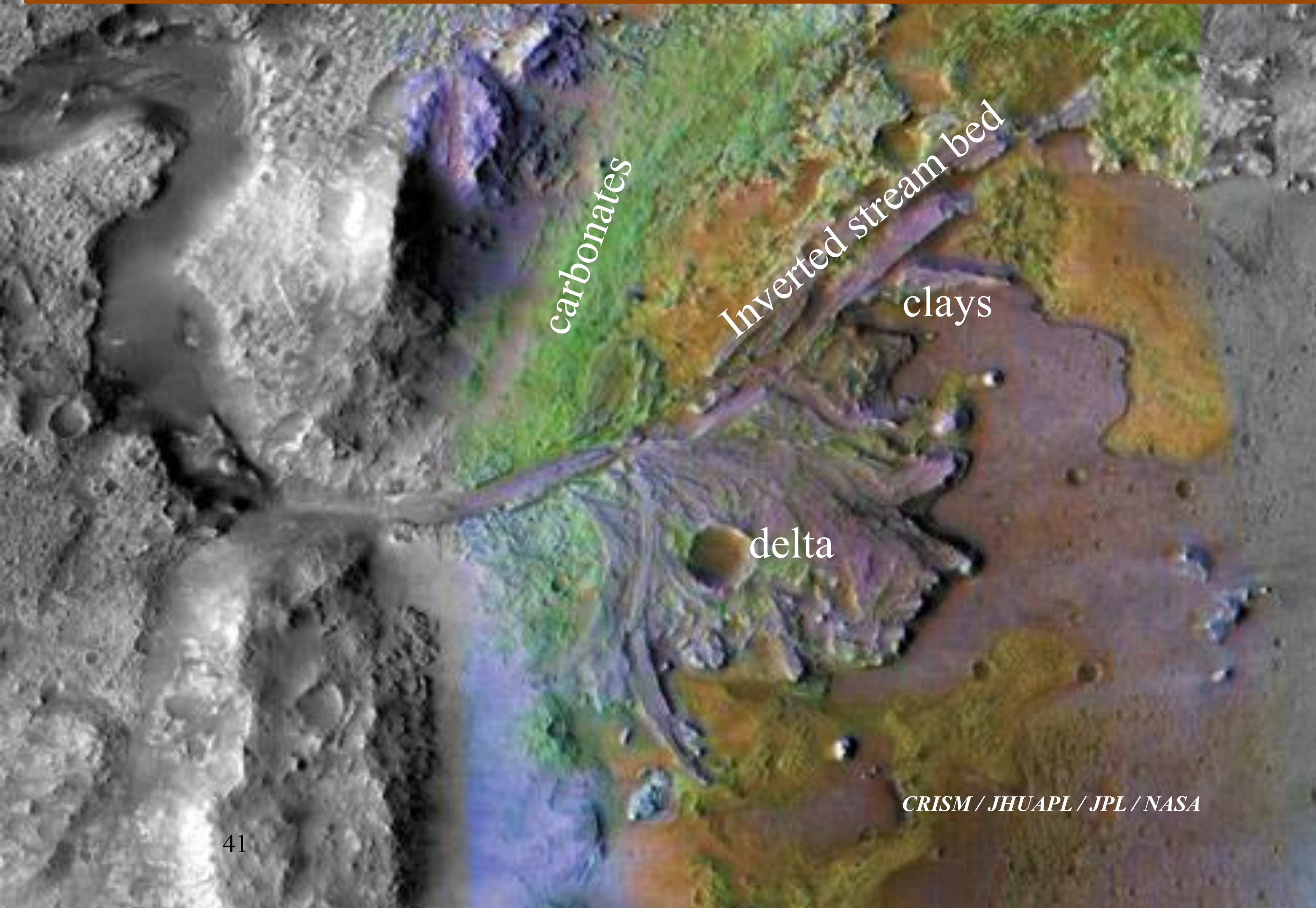
Science

- *Assess past habitability of an astrobiologically relevant ancient environment on Mars*
- *Assess biosignature preservation potential with the environment and search for biosignatures*
- *Assemble cached samples for possible future return to Earth*

Technology

- *Advance technologies with applications to future human and robotic explorations objectives*

MRO & Landing Sites: Jezero Crater



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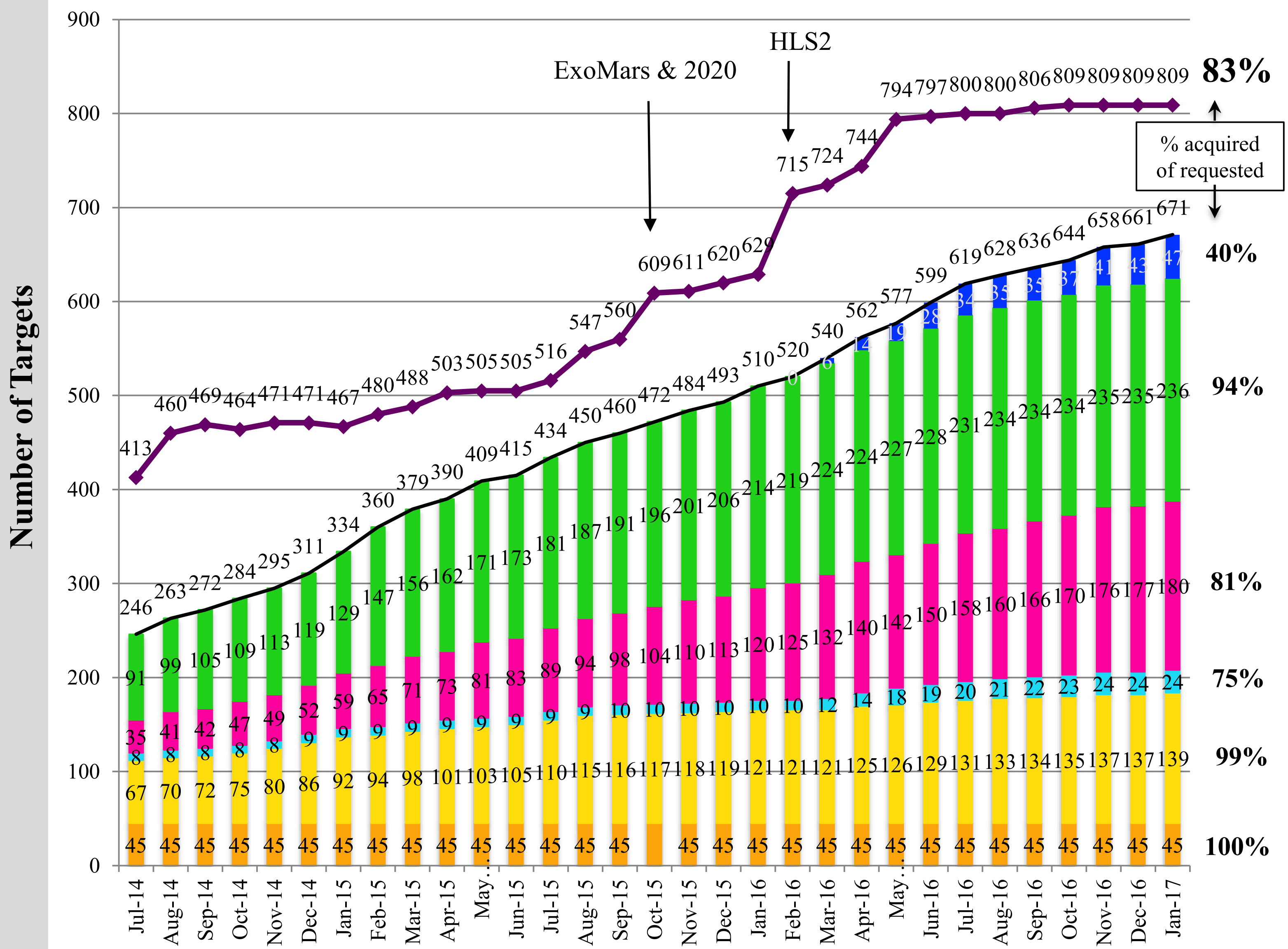
Progress on Landing Sites



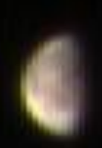
Note:
- *The data shown does not account for the number of attempts made per target.*
- *MSL counts are shown from MSL EDL (8/2012)*
- *There are 5 additional 2020 acquired targets for HiRISE against the list that are not shown (taken prior to 8/2012)*

**this includes up to rm267_1b final IPTFs*

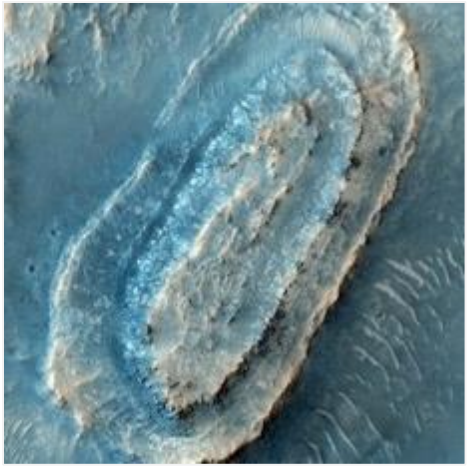
MRO: More to Come!

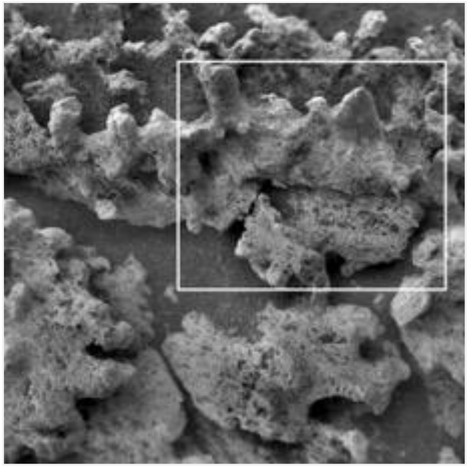
MRO continues to operate nominally in its dual-purpose mission of scientific observation and programmatic support

- ***MRO is working to ensure spacecraft operability through 2023 (2020 Rover Prime Mission)***
  - All-Stellar Mode being developed to preserve IMU lifetime
  - Eclipse power management being instituted to extend battery life
  - Onboard fuel adequate for nominal operations and critical event support (2018 *InSight,* 2020 Rovers)
  - Landing site reconnaissance for *InSight*, *2020 Mars* & *ExoMars* rovers continues
  - Preparing to support EDL and surface relay for *InSight* and *Red Dragon* – Continuing relay support for MER and MSL
- ***Exciting EM4 mission is in progress with all instruments operating***
  - 1 of 3 CRISM coolers continuing to yield good data in bimonthly cold cycles
  - HiRISE detector aging mitigated by warm-ups
  - MCS, MARCI, CTX, SHARAD show no signs of aging



Earth (and Moon) as seen by MRO on Nov 20th from Mars orbit.
Acquired at a range of 205 million km (~200 km/pixel)





JEZERO

- Deltaic/lacustrine deposition with Hesperian lava flow and hydrous alteration
- Evidence for hydrous minerals from CRISM, *including carbonates*

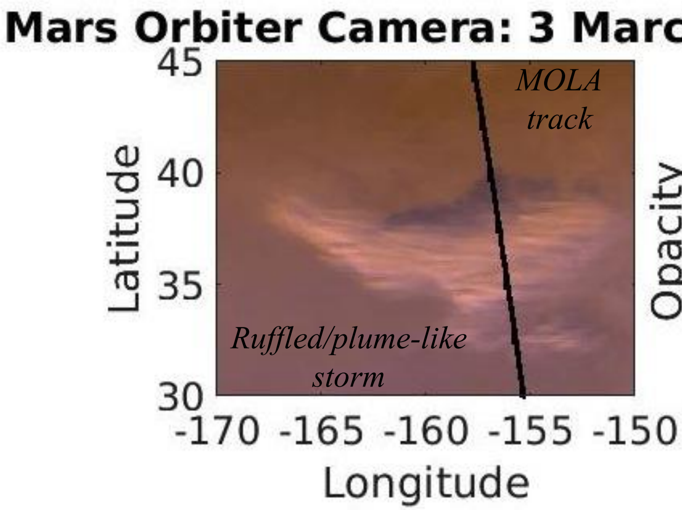
NE SYRTIS

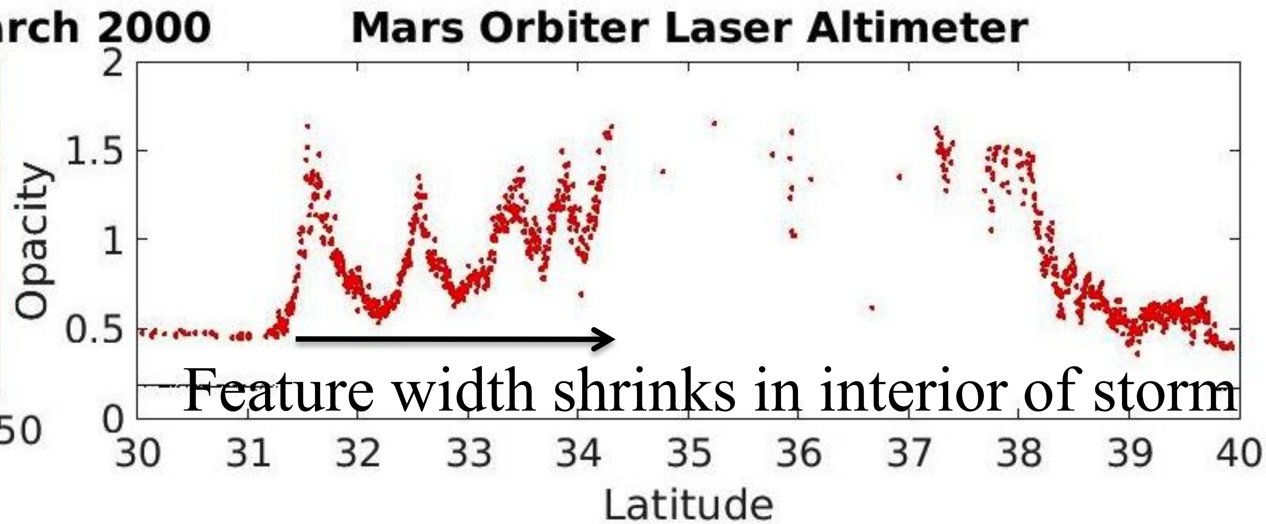
- Extremely ancient igneous, hydrothermal, and sedimentary environments
- High mineralogic diversity with phyllosilicates, sulfates, carbonates, olivine
- Serpentinization and subsurface habitability?

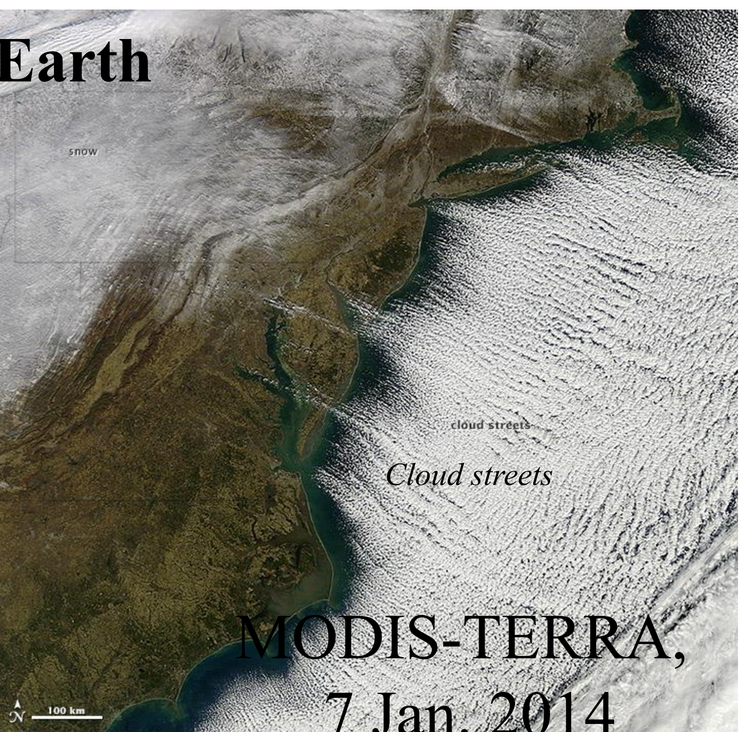
COLUMBIA HILLS

- Carbonate, sulfate, and silica-rich outcrops of possible hydrothermal origin and Hesperian lava flow
- Potential biosignatures identified
- Previously explored by MER

Structure of One Major Type of Martian Dust Storm Suggests They Are Driven by Strong Winds Behind Cold Fronts







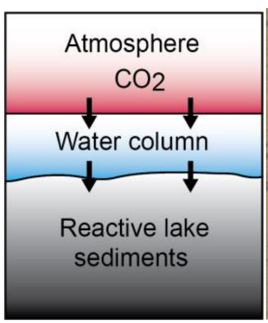
Dust storms on Mars have three major types of cloud-top structures in visible imagery. One type (ruffled/plume-like) is commonly observed in a very smooth area with a dusty surface in Mars's northern plains. Using observations from multiple types of instruments on MGS and MRO, it was found that the elongated linear features in these storms strongly resemble cloud streets in the Earth's atmosphere, particularly the type known as "wide, mixed layer rolls." On Earth, these form over bodies of water after the passage of cold fronts. The storms on Mars likely have a similar dynamical origin, with the dusty Martian surface acting like a body of water.

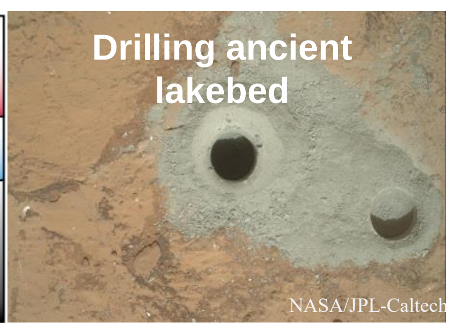
For more details, see: N.G. Heavens (2017), Textured Dust Storm Activity in NE Amazonis–SW Arcadia, Mars: Phenomenology and Dynamical Interpretation, accepted by *J. Atmos. Sci.*

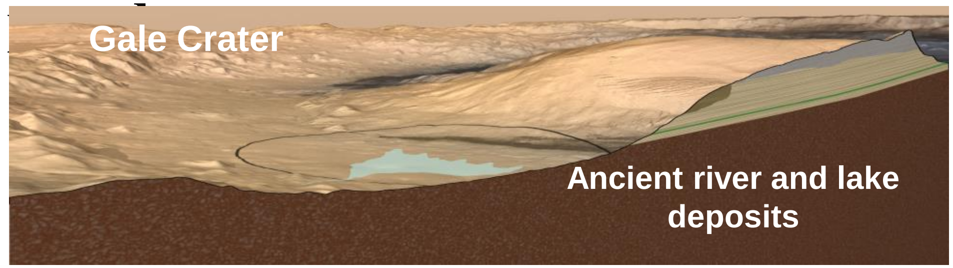
Curiosity: Little CO_2 in Ancient Mars Atmosphere

Examining minerals in mudstones formed at the bottom of a lake three and half billion years ago on Mars deepens the 'faint young Sun'

- Satellites have spent decades looking for carbonate minerals on Mars – the remnants of a thick carbon dioxide rich atmosphere thought to have helped keep the planet warmer early in its history than today, despite a dimmer Sun.
- Carbonate minerals are not as common as expected, but may be buried deep within the crust or covered in dust, limiting visibility from space.







- The Mars Science Laboratory (MSL) *Curiosity* Rover sampled ancient lake sediments in Gale Crater containing basaltic minerals that should have reacted to form carbonates if a thick carbon dioxide atmosphere were present. CheMin, an X-ray diffraction instrument on MSL that detects minerals, has not found any carbonates. This limits carbon dioxide to tens to hundreds of times lower than levels required by some Mars climate models in which lakes and rivers can form and flow on the surface without freezing.
- Other ways to keep ancient Mars warm enough to explain evidence of river networks and lakes widespread across the planet in older terrains are needed.

Bristow et al. 2017- *PNAS*

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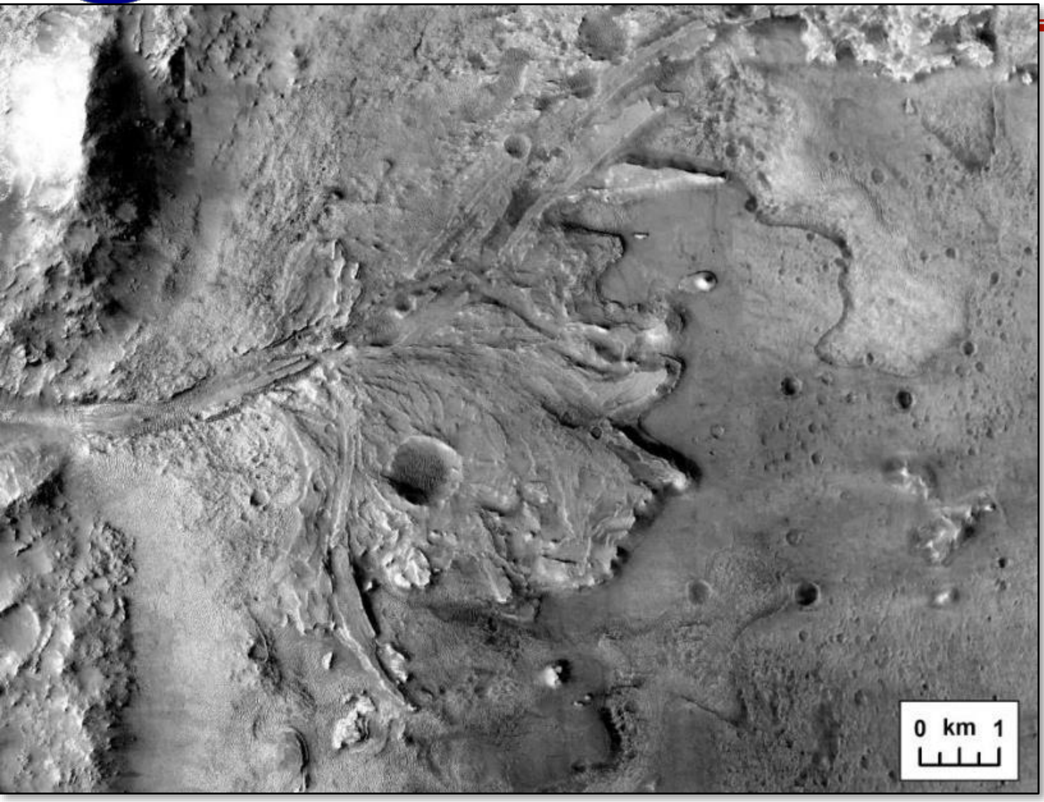
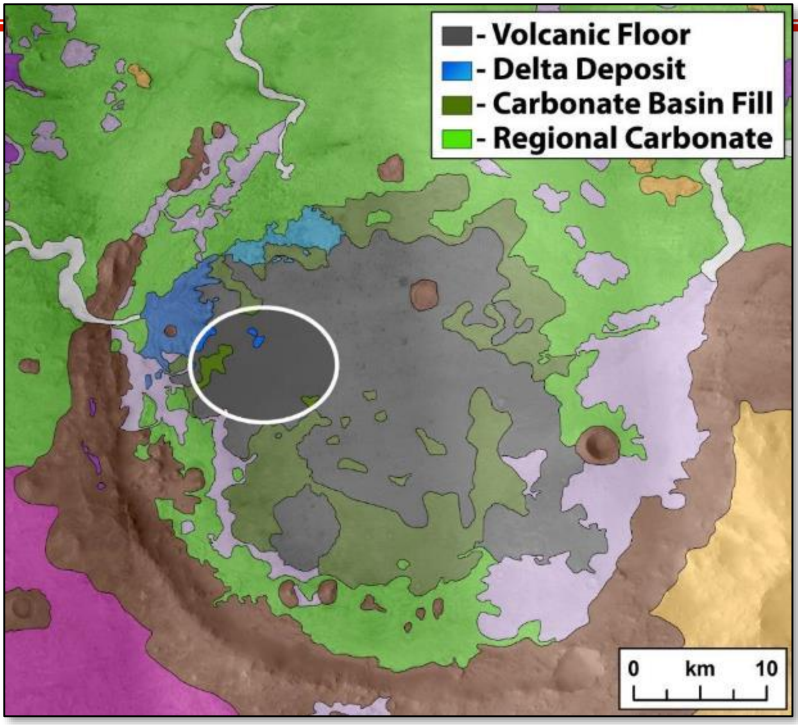
Jezero Crater



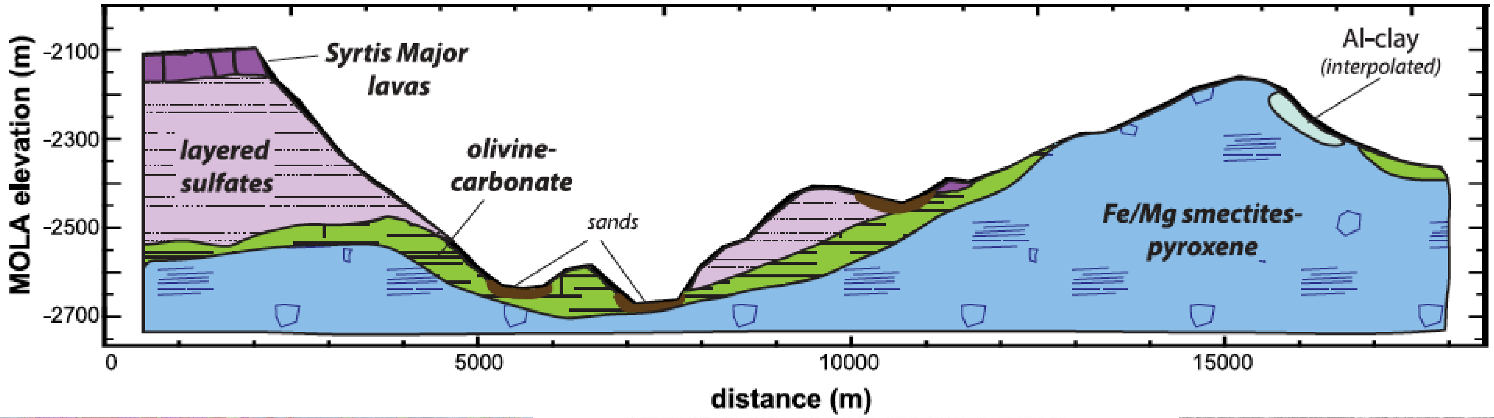


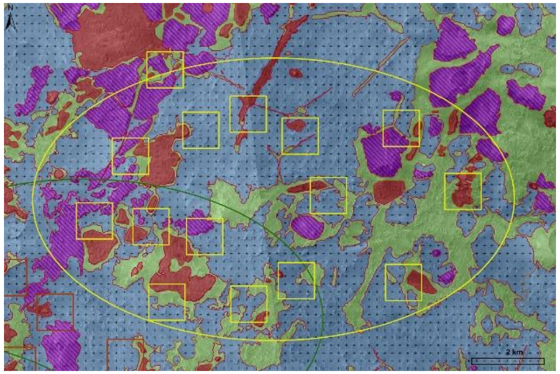
from T. Goudge presentation at LSW3

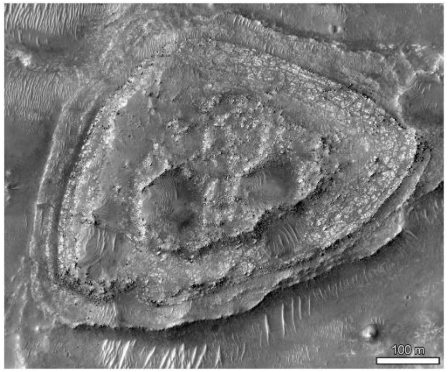
Positives: Oldest crater lake site (Noachian), with well-defined fine-grained deltaic facies attractive for biosignature investigation. Large, geologically diverse headwaters region. Carbonate bearing unit that may preserve record of ancient climate. Deep open-basin lake.

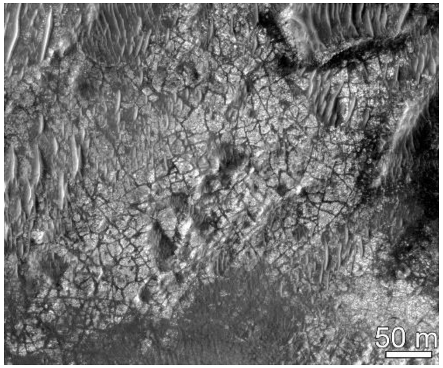
Slide courtesy of Ken Farley, M2020 Project Scientist

NE Syrtis









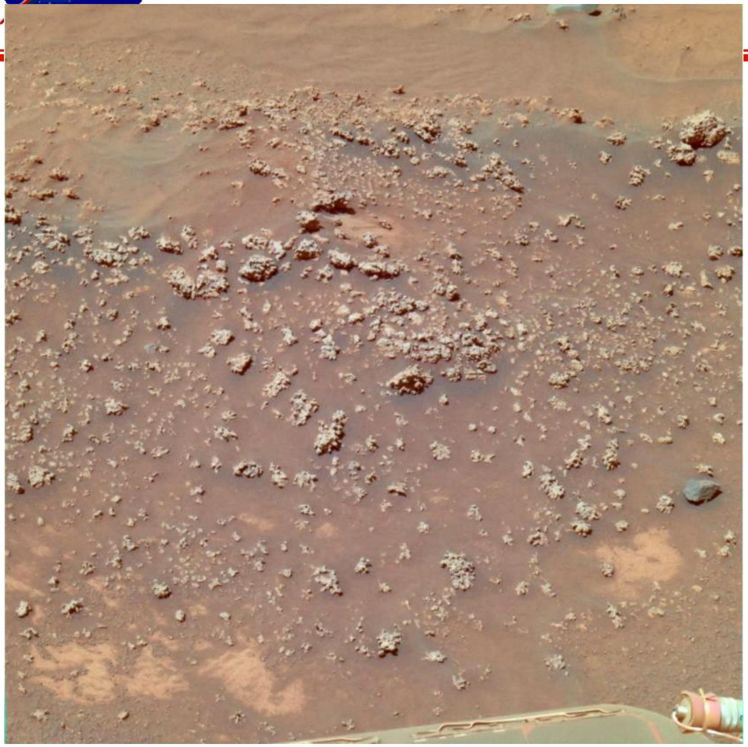
from J. Mustard and M. Bramble at LSW

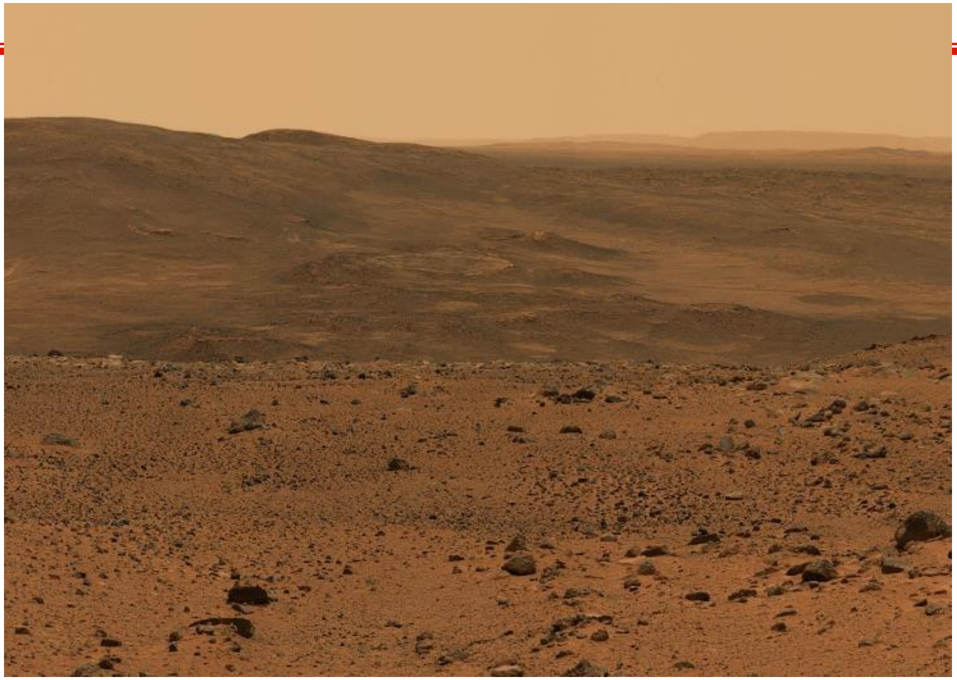
Positives: Lithologic diversity spanning long period of early Mars. Clear, readily accessible stratigraphy within the ellipse. Isidis(?) megabreccia, phyllosilicates, abundant carbonates in stratigraphy (subsurface aquifer?, serpentinizing system?).

Negatives: In-ellipse mafic unit may not be volcanic. In-place Syrtris Major lavas probably too distant from ellipse to reach.

Mars Reconnaissance Orbiter

Columbia Hills





from presentations by S. Ruff and R. Arvidson at LSW3

Positives: Digitate silica structures possibly from ancient hot spring may be potentially habitable environment with high preservation potential. Diverse igneous suite. Highly rated by RSSB.

Negatives: Origin/age of key silica deposit is disputed. Environment is dusty, impeding instrument performance. Site has already been investigated with a capable rover, making it less clear what original contributions Mars 2020 can make in-situ.

Closing on the Final Landing Site List

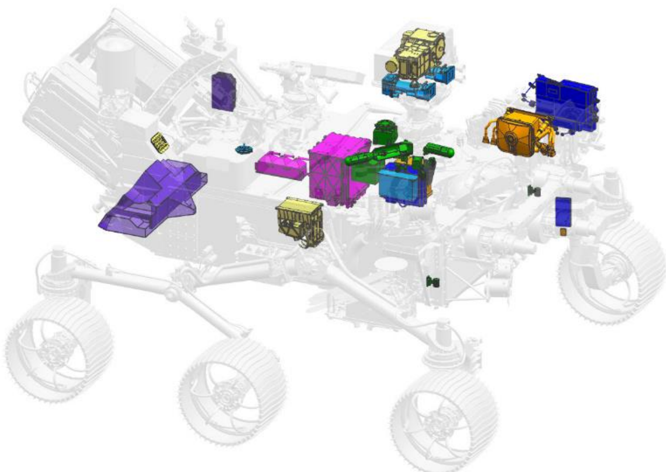
1. Project Engineering and Science will continue to work closely together to assess any operational challenges at the highly rated sites.

2. The Mars 2020 PSG and science team will critically assess the pros, cons, uncertainties and risks of the highly rated sites. We will work to develop a science plan at each site (including evaluation of specific regions of interest), and what could be accomplished both in-situ and in terms of cached samples.

3. For Columbia Hills, further assessment of the silica target's origin is being undertaken, as will evaluation of any challenges for its study/collection by the rover. The Mars 2020 PSG will consider how and to what extent the rover's instrument suite can advance scientific knowledge at this previously visited site.

Slide courtesy of Ken Farley, M2020 Project Scientist

Science Instruments



Instrument Key
Mastcam-Z Stereo Imager
MEDA Mars Environmental Measurement
MOXIE In-Situ Oxygen Production
PIXL Microfocus X-ray fluorescence spectrometer
RIMFAX Ground Penetrating Radar
SHERLOC Fluorescence and Raman spectrometer and Visible context imaging
SuperCam LIBS and Raman

Full complement of instruments is still under development, with no reduction in capabilities

Five of seven instruments have had their Critical Design Review (only MEDA and PIXL remain)

Some Updates:

1) MEDA schedule is tight
2) Good progress is being made resolving SHERLOC (laser) and PIXL (x-ray tube) technical challenges

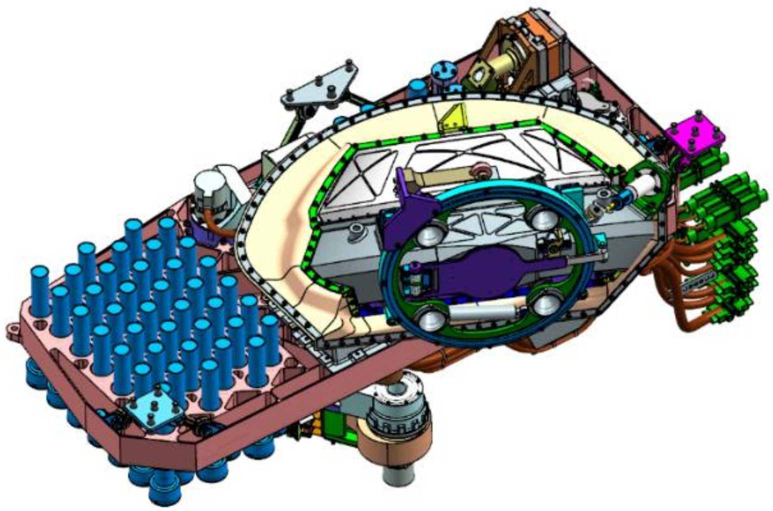
Sampling and Caching System (SCS)

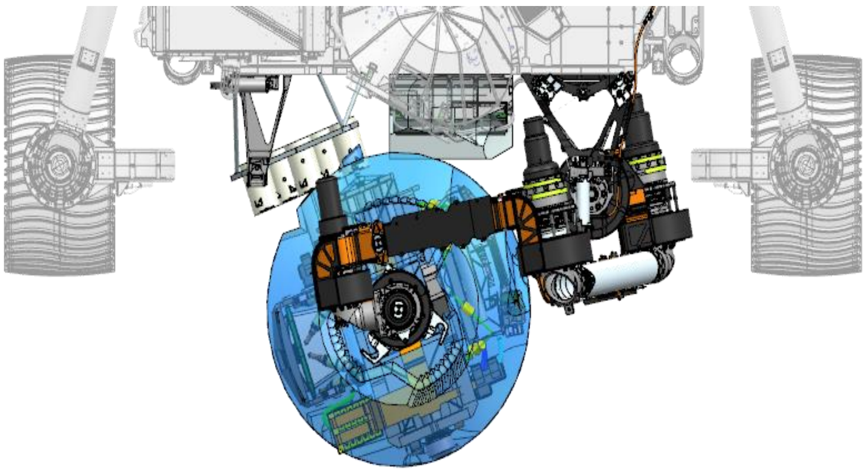
The very complex robotic SCS passed its subsystem CDR earlier this year

Carries ~40 sample tubes (31 + science/engineering spares)

Carries 6 witness tubes (in the 40) from which to acquire round-trip contamination knowledge
- witness tube design is currently under development

Contamination requirements remain unchanged and good progress is being made in achieving them (e.g., 10 ppb TOC baseline, 40 ppb threshold)





Slide courtesy of Ken Farley, M2020 Project Scientist

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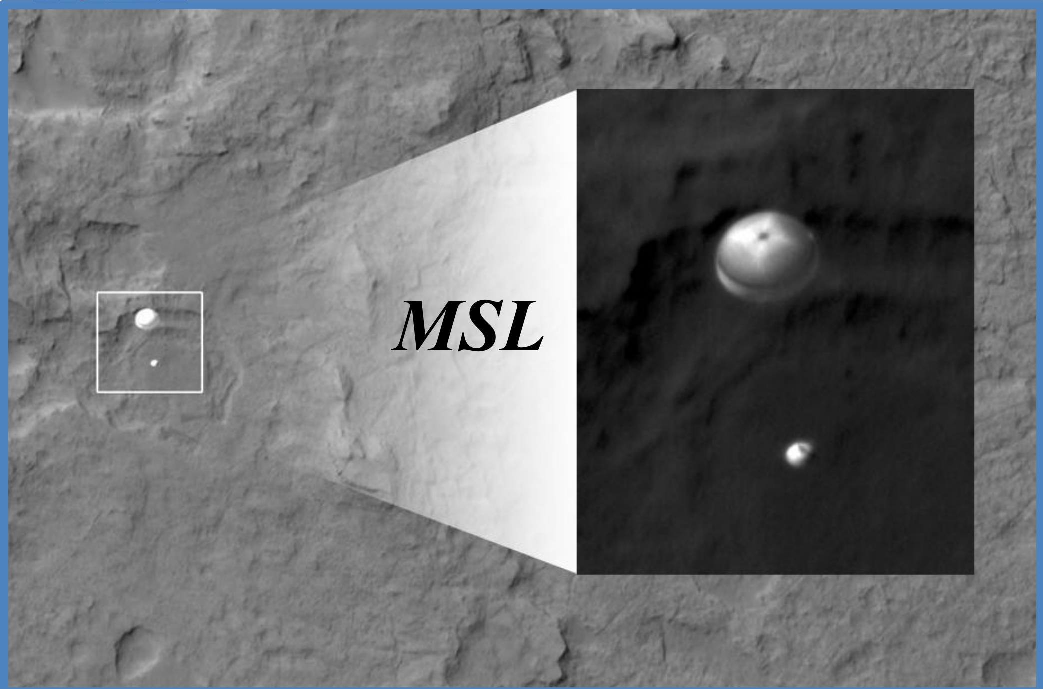
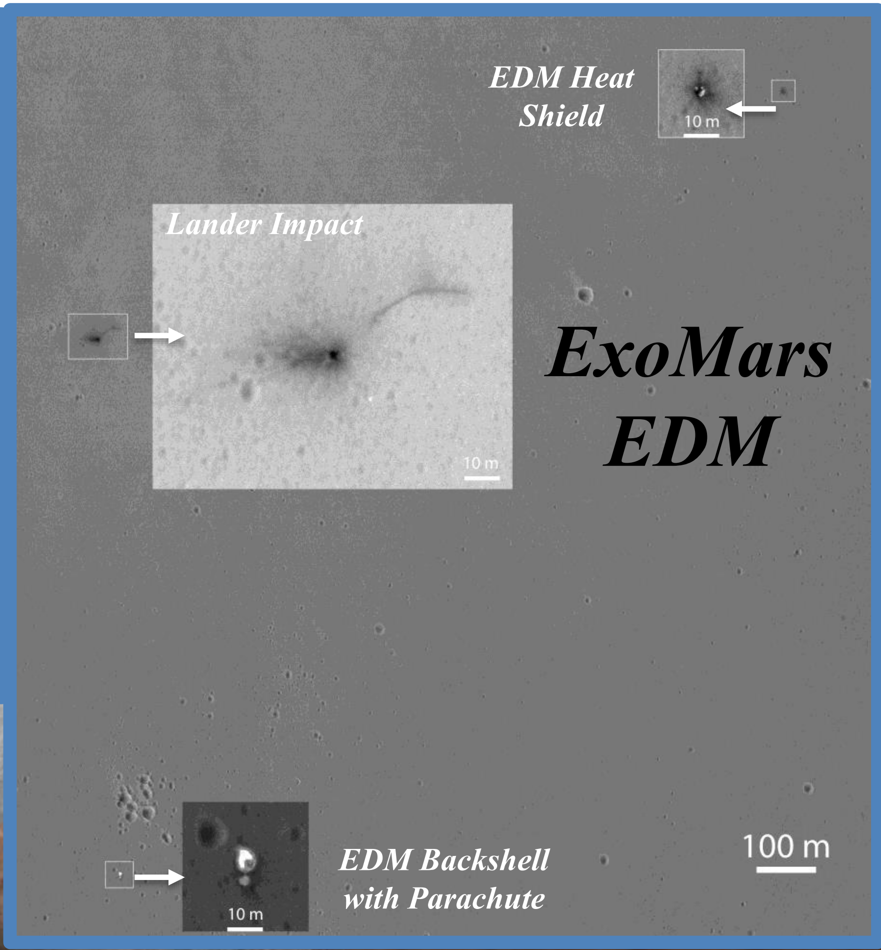
Mars Reconnaissance Orbiter

MARS Program Support by MRO

JPL





HiRISE / U. Arizona / JPL / NASA

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Other Ongoing and Future missions

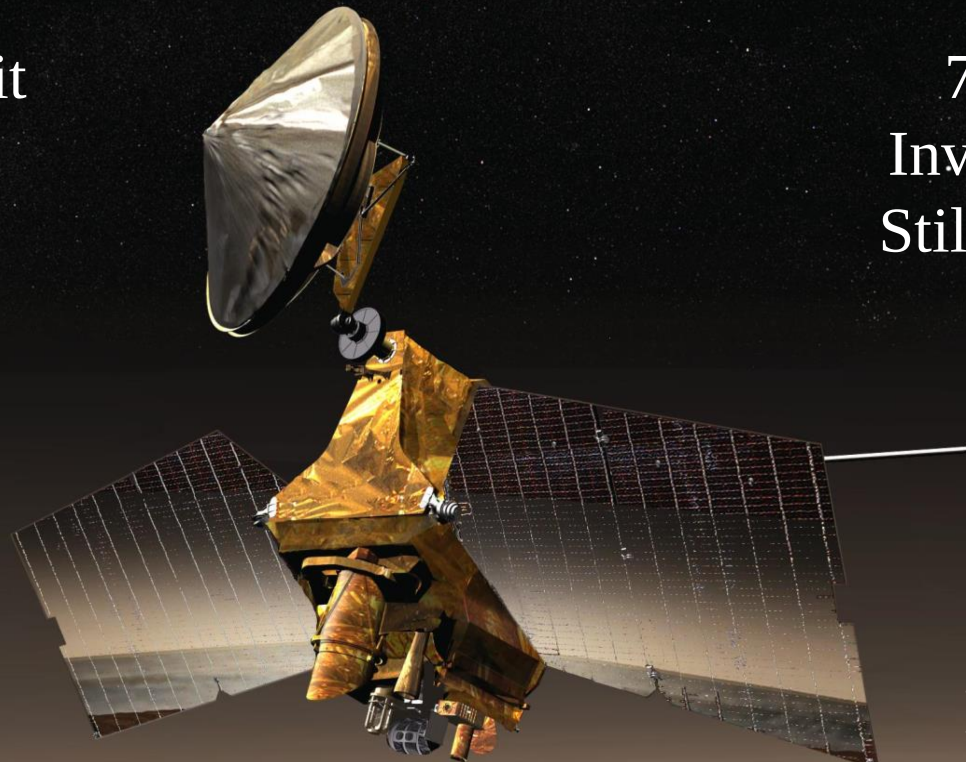
- Indian space agency - MOM
- Red Dragon ~ 2020
- Chinese program

11 Years in Orbit

~50,000 orbits

300 Tb of Science Data Returned

~200 kg of Usuable Fuel still in the Tank



7 Science Investigations Still Returning Data

More Discoveries Sure to Come!

Mars Reconnaissance Orbiter

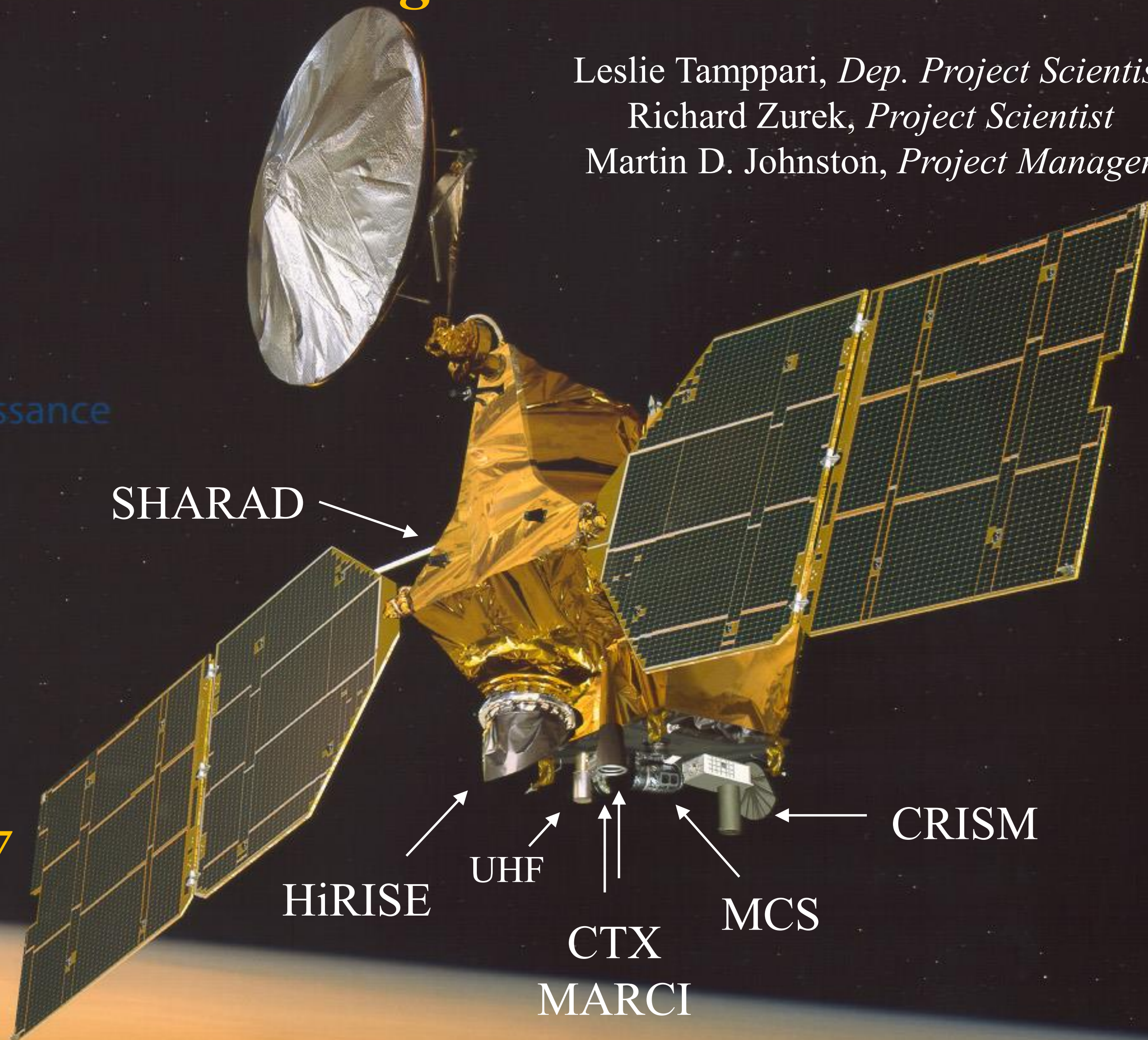
Government sponsorship acknowledged.

Backup

MRO: Continuing Discoveries at Mars

Leslie Tamppari, *Dep. Project Scientist*
Richard Zurek, *Project Scientist*
Martin D. Johnston, *Project Manager*

Mars
Reconnaissance
Orbiter



Presentation
to MEPAG
February 23, 2017

CL#17-0802

The University of Arizona.
MIT
Malin Space Science Systems
agenzia spaziale italiana
Lockheed Martin